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THE CONSTRUCTION OF ROADS AND PAVEMENTS

THE CONSTRUCTION OF ROADS AND PAVEMENTS

BY

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PREFACE TO THE FOURTH EDITION

The Construction of Roads and Pavements was originally written as a textbook to be used in the basic course in highway engineering for students in Civil Engineering. As each revision has been in progress, there has been a temptation to include a variety of material that is interesting and valuable but is perhaps more suitable for reference purposes than for a textbook. It has seemed best, however, to adhere to the original plan and to avoid increasing the size of the treatise beyond that which is necessary for the presentation of the fundamental principles of the design and construction of roadway surfaces.

The student really needs a general idea of the systems of management of road systems to serve as a background for the study of design and construction and the first chapter is intended to afford that background. Subsequent chapters follow a logical order in which the several types of engineering work are treated in the order in which they will generally be undertaken in highway projects. The discussion of types of surfaces begins with the simpler types and leads up to the more truly technical considerations involved in the construction of the high types. Finally, there is a presentation of some of the economic phases of the subject.

The student will generally profit greatly by solving problems of the right kind along with his study of the text and accordingly there are numerous problems included in this edition. It is highly desirable that problems have a local setting, if that is possible, and, consequently, those included in the text are perhaps little more than suggestive, although most of them are used in the course at Iowa State College.

In many places, statements are made about principles, or construction methods, with but little explanation because of the desire for brevity, but at such places a reference is given to the authority for the statement.

The author has drawn freely on the wealth of material that has been the outgrowth of highway research, of which there has been a great volume during the past five years. Research

and the progressive atmosphere that pervades many of the state and municipal highway engineering organizations are rapidly placing highway construction on a sound technical basis and at the same time creating a more exacting standard for the teacher. This is perhaps adequately reflected in the added emphasis given in this treatise to the theory of design and to economic considerations.

While illustrative material in the form of examples of good practice is still retained to a limited extent, it has been deemed advisable to include lists of useful references at the end of certain chapters, in lieu of the excerpts employed in previous editions. This has been done to provide collateral reading for advanced students and to insure a substantial amount and variety of illustrations of the trend of practice.

The author wishes to acknowledge his indebtedness to Ralph A. Moyer for assistance in selecting material and for his painstaking review of the manuscript; to Lowell O. Stewart, who rewrote the chapter on highway surveys; to Raymond Paustian and Samuel C. Whitehouse who prepared most of the drawings and assisted in the work of assembling and arranging the manuscript; and to Anna Vanderlinden who performed the secretarial work.

The author also wishes gratefully to acknowledge the many very helpful suggestions he has received from teachers and students with reference to the parts of the book that needed revising.

THOMAS R. AGG.

AMES, IOWA
August, 1929

PREFACE TO THE FIRST EDITION

"The Construction of Roads and Pavements" was written to meet the need for a concise presentation of approved practice in the construction of roads and pavements and of the principles involved.

The book is intended primarily for use as a text in a two or three-hour course in roads and pavements, but numerous tables and typical designs and specifications have been included that should add to its value as a reference book for highway engineers.

The ultimate object of all highway engineering is the construction of durable and well-designed roadway surfaces. The attainment of this object involves selecting and testing the materials, assembling those that are suitable, and incorporating them in the roadway surface. A knowledge of the construction of roads and pavements is therefore the basis of highway engineering.

Much of the material used in the text has been prepared from notes that have been accumulating for several years. During that time the author has attended numerous conventions of highway engineers and has often discussed the various problems of roadway construction with engineers with whom he has been associated. Doubtless many of the ideas expressed in the text have thus unconsciously been absorbed. A considerable amount of material has been obtained from current periodical literature and acknowledgment has been given for material abstracted from the writings of other engineers.

The author is especially indebted to Mr. T. H. MacDonald, Chief Engineer of the Iowa Highway Commission, for his assistance and encouragement; to Mr. J. W. Eichinger, Editor of the Iowa Service Bulletin, for valuable suggestions and especially for furnishing photographs for cuts; to the Illinois Highway Department for much valuable data, and to a score or more other highway engineers who have furnished plans, specifications, photographs or data on construction.

Special acknowledgment is made of the very valuable assistance of Mr. C. S. Nichols, assistant to Dean of Engineering, Iowa State College, who has assisted in the preparation and arrangement of the manuscript.

T. R. Agg.

August, 1916.

CONTENTS

Page

Preface to the Fourth Edition v

Preface to the First Edition vii

CHAPTER I

The Development of Highway Systems 1
Social Considerations—Educational Considerations—Economic Considerations—Engineering Considerations—United States Highways—State Trunk Highways—Main Market Roads—Local Roads—Urban Highways—Streets—Significance of Classification of Highways—Federal Authority—State Authority—County or District Authority—Township Authority—Evolution of Highway Finance—Theory of Highway Finance—General Benefits—Special Benefits to Land—Special Benefits to Traffic—Equity—Ability to Pay—Revenues Based on General Benefits—Revenues Based on Special Benefits to Land—Bonds—Administrative Systems—Systems of Financing—Special Assessments for Pavements—Items of Cost Assessed—Front Foot Rule for Assessments—Area Method of Assessment—Zone and Area Method—Benefit Factor Method—Assessing Irregular Shaped Parcels—Methods of Ordering Pavements—How Type of Pavement is Selected—Problems.

CHAPTER II

Surveys and Plans for Roads and Pavements 32
Reconnaissance Surveys—Surveys for Earth-road Construction—Complete Detailed Surveys—The Preliminary Survey—The Center-line Survey—Stationing—Staking the Center Line—Referencing Transit Points—Intersection Angles—Horizontal Curves—Topographic Features—Corner Stones—Datum and Bench Marks—Cross-sections—Intersecting Roads and Driveways—Topographic Surveys for Bridges and Grade Separations—Right-of-way Surveys—Construction Surveys—Slope Stakes—Finishing Stakes—Pavement Stakes—Staking Bridges and Culverts—Referencing Land Monuments and Transit Points—Final-estimate Surveys,—Road Plans:—Profile—Plan View—Cross-sections—Surveys for City Paving:—Monuments—Stakes—Plat—Profiles—Cross-sections—General Information—Problems.

CHAPTER III

Drainage and Control of Erosion 52
General Problem—Side Ditches—Run-off—Shape of Ditch—Supplementary Ditches—Drainage of Embankments—Tile to

PAGE

Supplement Side Ditches—Ground Water—Subgrade Drainage:—Drainage in Arid and Semi-arid Regions—Run-off—Erosion—Purpose of Culverts—Reinforced Concrete Culverts—Pipe Culverts—Headwalls—Paved Fords,—Control of Erosion:—Controlling Erosion of Ditches—Controlling Erosion of Side Slopes—Control of Stream Erosion—Problems.

CHAPTER IV

ECONOMICS OF HIGHWAY GRADES 71
Characteristics of Traffic—Plus Grades—Momentum Effects—Minus Grades—Grades for Commercial Vehicles—Rate-of-grade Diagrams—Effect of Excessive Grades—Excessive Minus Grades—Procedure in Establishing Grades—Experimental Coefficients—Tractive Resistance—Rolling Resistance—Air Resistance—Grades for Animal-drawn Vehicles—Problems.

CHAPTER V

THE DESIGN OF RURAL HIGHWAYS 87
Width of Right-of-way—The Cross-section—The Roadway—Width—Traffic Capacity—Cross-slope—Superelevation—Drainage Ditches—Alignment—Directness—Grades—Safety—Esthetics Horizontal Curves—Easements—Width of Curves—Vertical Curves at Summits—Vertical Curves in Sags—Rolling Grade Lines—Balancing Earthwork—Computing Quantities—Shrinkage and Swell—Settlement—Subsidence—Overhaul—Guard Fences—Guide and Warning Signs—Foot Paths—Camp Sites and Comfort Stations—Problems.

CHAPTER VI

THE DESIGN OF STREETS 111
Width of Pavement—Local Streets—Through Streets in Residential Districts—Retail Business Streets—Warehouse and Wholesale District Streets—Street-car Tracks—Longitudinal Grades—Maximum and Ruling Grades—Minimum Grades—Curb Elevations—Relation of Pavement to Curbs—Unsymmetrical Cross-sections—Purpose of Crown—Form of Crown—Amount of Crown—Types of Intersection—Curb Radii at Intersection—Elevations at Intersections—Surface Drainage—Drainage Principles—Pedestrian Crossings—Cross-drains—Storm-water Inlets—Gutter Inlets—Curb Inlets—Combined Curb and Gutter Inlets—Catch Basins—Curbs:—Dimensions—Foundations—Expansion and Contraction—Ornamental Gutters—Concrete for Curbs—Armored Curb—Sidewalks—Width of Walks—Cross-slope—Two-course Concrete Walks—One-course Concrete Walks—Expansion and Contraction Joints—Ornamental Walks—Tinted Concrete Walks—Bituminous Walks—Pebble Concrete Finish—Tile Walks—Gravel Walks—Design of Street Intersections—Streets with

PAGE

Grades less than 2 Per Cent—Streets with Grades over 2 Per Cent—Car-track Paving—Types of Car-track Rails—T-rails—Grooved Rails—Lipped Rails—Track Construction.

CHAPTER VII

THE CONSTRUCTION AND MAINTENANCE OF EARTH ROADS 158
General Characteristics of Soils—Clay—Design—Cross-sections—Snow and Water—Sand Drifts—Swamp Roads—Grade Reduction—Blade Grader Work—Elevating Grader Work—Scraper Work—Steam-shovel Excavation—Reshaping and Light Grade Reduction—Elevating Grader Work—Classes of Road Work for Elevating Grader—Construction Methods—Blade Grader Work—Maintenance—Machinery Used for Earth-road Work—Picks, Mattocks—Shovels, Spades—Plows—Rooter Plows—Harrows—Slip Scrapers—Fresno Scrapers—Wheel Scrapers—Road Graders—Elevating Graders—Levelers—Maney Grader—Dump Wagons—Trucks—Road Drags—A Few Road Dragging Rules—Problems.

CHAPTER VIII

SAND-CLAY ROADS 175
Gumbo—Slaking Clay—Semi-plastic Clay—Sand-clay Soils—Loam—Sand—Gypsum—Sand-clay Construction on Gumbo, Clay or Loam—Sand-clay Construction on Sand—Characteristics—Problems—An Investigation of Sand-clay Road Surfaces—Method of Construction—Construction with Artificial Mixtures—Durability and Maintenance.

CHAPTER IX

GRAVEL ROADS. 187
Materials—Wearing Qualities—Bonding Properties—Ideal Gravel—Grading—Selection of Gravel—Preparation of Roadbed—Width and Thickness of Gravel—Cross-slope—Placing the Gravel by Trench Method—Feather-edge Method of Placing Gravel—Placing Gravel on Sandy Soil—Washed Gravel—Maintenance—Cost of Gravel Roads—Sand-coated Roads—Characteristics of Gravel Roads—Crushed Stone and Gravel Surfacing:—Design of Cross-section—Size of Surfacing Material—Distribution of Surfacing Material—Problems.

CHAPTER X

WATER-BOUND MACADAM ROADS AND PAVEMENTS. 201
Materials—Quality of Rock—Size of Stone in Surface Layer—Size of Stone in Lower Course—Size of Stone for Telford Foundation—Crusher-run Stone—Construction of the Surface—Thickness of Macadam—Quantity of Stone Required—Roadbed and Shoulders—Placing the Stone—Blind Drains—Rolling—Applying Screen-

PAGE

ings—Puddling—Finishing the Shoulders—Maintenance—Costs—Stone Forks—Stone Rakes—Narrow-gage Dump Cars for Hauling—Motor Trucks—Loading Devices for Materials—Self-propelled Rollers—Scarifiers—Portable Stone-crushing Plants—Stationary Crushing Plants—Problems—Examples of Good Practice—Useful References.

CHAPTER XI

ROAD SLABS OF CONCRETE 223
Wheel Load—Static Wheel Load—Impact Load—Dynamic Load—Equivalent Static Load—Impact Reaction—Highway Loads—Impact—Impact Stresses—Temperature Stresses—Linear Changes—Curling—Effect of Moisture—Effect of Superimposed Wheel Loads—Subgrade Support—Fills at Bridges and Culverts—Effect of Wearing Surfaces—Strength—Load Distribution—Temperature Effects—Effect of Imbedded Steel—Purpose of Reinforcement—Transverse Steel—Longitudinal Steel—Value of Dowel Steel—Theory of Design of Slab Cross-section—Older's Theory of Design—Basis of Design—Procedure in Design—Illustrative Designs.

CHAPTER XII

PORTLAND-CEMENT CONCRETE ROADS AND PAVEMENTS 244
Cross-sections—Design of Expansion and Contraction Joints:—Expansion Joints—Contraction Joints—Detail of Expansion Joints—Fillers for Expansion Joints—Details of Contraction Joints—Planes of Weakness—Joint Formers—Longitudinal Joints—Methods of Reinforcing—Storm-water Flumes and Inlets—Integral Curbs for Pavements—Concrete Aggregates—Broken Stone for Coarse Aggregate—Gravel Aggregate—Slag for Coarse Aggregate—Sandstone for Coarse Aggregate—Size of Coarse Aggregate—Fine Aggregate—Materials for Two-course Pavements—Concrete Mixtures—Measuring Materials—Construction Details—Preparation of Subgrade—Forms—Water Supply—Proportioning Plants—Dry Batch Method of Proportioning—Wet Batch Methods of Placing Concrete—Mixing the Concrete—Machine Finishing—Water Curing—Calcium-chloride Curing—Bituminous Coatings for Curing—Sodium Silicate—Finishing Methods for Wide Streets—Curing Period—Resurfacing Concrete Roads and Pavements—Problems.

CHAPTER XIII

VITRIFIED BRICK PAVEMENTS 272
Paving Brick—Laminations—Kiln Marks—Checks—Kinds of Paving Brick—United States Standard Paving Bricks—Repressed Vitrified Brick—Non-repressed Brick—Wire-cut Lugs—Vertical Fiber Brick—Standard Lugless Brick—Physical Characteristics of

PAGE

Paving Brick—Wearing Qualities—Cross-breaking Test—Regularity of Shape—Foundation Courses—Concrete Base for Bituminous-filled Brick Surface—Concrete Base for Grout-filled Brick Surface—Materials for the Concrete—Macadam-base Foundation—Brick Foundation—Curbs—Sand Bedding Course—Mortar Bedding Course—Bituminous-mastic Bedding Course—Granulated Slag and Screenings for Bedding Course—Fillers for Brick Pavements—The Grout Filler—Bituminous Fillers—Squeegee Method—Quantity of Filler Required—Quality of Bituminous Filler—Asphalt Filler—Bituminous-mastic Filler—Expansion Joints—Brick Rural Highways—Design—Construction Methods—Earth Subgrade—Placing Foundation Course—Placing the Bedding Course—Laying the Brick—Rolling the Brick—Monolithic Brick Pavements—Problems.

CHAPTER XIV

WOOD BLOCK PAVEMENT. 292

Design of Cross-section—Curbs—Kinds of Timber Used—Size of Blocks—Quality of the Blocks—Character of Preservatives—Creosote Oil—Mixtures of Tar and Creosote—Creosote Oil Specifications—Coal-tar Paving Oil—Coal-tar Distillate Oil—Quantity of Preservative—Bleeding—Cutting of Blocks—Seasoning and Treating—Inspection of Blocks—Mortar Bedding Course—Paint-coat Bedding Course—Filler for Wood-block Pavements—Method of Laying—Expansion Joints—Characteristics—Problems—Example of Good Practice.

CHAPTER XV

STONE-BLOCK PAVEMENTS 309

Design of Cross-section—Kinds of Stone Used for Paving Blocks—Quality of Blocks—Size of Blocks—Thickness and Depth of Block—Special Kinds of Blocks—Grooved Blocks—Stone Cubes—Uniformity of Paving Blocks—Requirements for Blocks—Sand Bedding Course—Mortar Bedding Course—Laying the Blocks—Tamping—Pitch Fillers—Asphaltic Fillers—Cement-grout Fillers—Recut Granite Blocks—Characteristics of Granite Block Pavements.

CHAPTER XVI

BITUMINOUS ROAD AND PAVEMENT MATERIALS. 317

Asphalt—Orgin of Asphalt—Oil Asphalts—Definition of Asphalt—Bitumen—Value of Bitumens—Natural Asphalts—Trinidad Asphalt—Trinidad Petroleun—Bermudez Asphalt—Cuban Asphalt—Mexican Asphalt—Gilsonite—Natural Rock Asphalt—Refining Natural Asphalts—Petroleum Asphalts—Residual Asphalts—Gilsonite Products—Blown Oils—Tars—Cut-back Pitches—Water-gas Tar—Mixtures—Fluxes—Asphalt Cement—

PAGE

Classes of Commercial Bituminous Materials:—Asphalt Cements for Sheet Asphalt and Asphaltic Concrete—Fluxes—Creosote for Wood Preservation—Problems.

CHAPTER XVII

DUST LAYERS AND BITUMINOUS CARPETS. 334

Dust Suppression on Earth Roads and Streets:—Preparation—Grading—Kinds of Oil to Use—Applying Oil—Results to be Expected—Unloading the Oil from Tank Cars—Cost of Surface Oiling—Dust Suppression on Gravel and Macadam—Oil on Hard Pavement—Other Palliatives—Bituminous Carpets:—Purpose—Requirements of Bituminous Material—Applying the Bituminous Carpet—Bituminous Carpets on Worn-gravel and Macadam Roads—Bituminous Carpets on Concrete Roads—Examples of Good Practice—Useful References.

CHAPTER XVIII

PENETRATION AND MIXED MACADAM ROADS AND PAVEMENTS. 352

Penetration Macadam:—Design of Cross-section—Foundation Course—Sizes and Kinds of Stone—Bituminous Binders—Wearing Course—Rolling—Applying Bituminous Binder—Machinery and Appliances used for Bituminous Macadam Construction—Mixed Bituminous Macadam:—Stone for Mixed Macadam—Foundation—Wearing Surface—Oil Mix Macadam—Special Appliance—Sand and Stone Heaters—Melting Tanks—Mixers—Practice in Great Britain—Problems—Useful References.

CHAPTER XIX

SHEET ASPHALT AND ASPHALTIC CONCRETE SURFACES. 369

Sheet Asphalt:—Design of Cross-section—Foundation—Black Base—Water-bound Macadam Foundation—Gravel Foundation—Worn Block Pavements for Foundations—Binder Course—Open Binder—Close Binder—Character of Materials for Binder Course—Old Surface Mixtures for Binder—Surface Mixtures—Sand—Filler—Theory of Proportioning—Established Gradings—Asphalt Cement Required—The Pat Test—Proportioning Asphalt Cement—Construction of the Pavement—Smoothness—Some Features of Design—Characteristics of the Sheet Asphalt Surface.—Asphalt Block Pavements:—Composition of the Blocks—Size of Blocks—Subgrade—Foundation—Bedding Course—Laying the Blocks—Asphaltic Concrete:—Stone—Sand—Filler—Types of Asphaltic Concrete—Warrenite-Bitulithic—Foundation for Asphaltic Concrete—Thickness of Surface—Mixing and Placing—Laying the Surface—Dressing the Surface—Suburban Roads—Characteristics—Maintenance—Tools and Appliances Used for Sheet-asphalt and Asphaltic-concrete Construction—Mixing Plants—Problems.

CHAPTER XX

PAGE

ECONOMIC COMPARISONS OF ROADWAY SURFACES 398

Value of a Highway—Basis of Value—Unit of Measure—Life Tonnage—Economic Theory of Costs—Roadway Surface Costs:—Initial Cost—Maintenance Cost—Salvage Value—Economic Life—Computing Economic Life—Application to Highway Systems—Relation of Maintenance Costs to Volume of Traffic—Incidental Items of Cost—Maintenance of Right-of-way—Total Highway Costs—Relation between Type of Highway and Vehicle Costs—Combined Vehicle and Road Costs—Traffic Surveys—The Traffic Census—Traffic Weighing—Analysis of the Traffic Census—Unit of Traffic—Applications of the Traffic Census—Volume of Traffic—Weight of Traffic—Traffic Zones—Problems—Useful References.

CHAPTER XXI

SELECTION OF TYPE OF ROADWAY SURFACE. 423

Cost and Price Considerations—Physical Characteristics of Roadway Surfaces:—Color—General Appearance—Dustlessness—Ease of Cleaning—Character of Foothold—Special Local Considerations—Local Materials—Existing Types—Maintenance Organization—Recapitulation.

CHAPTER XXII

MAINTENANCE 428

Manitenance of Rural Highways:—Organization—Patrol Maintenance—Equipment of Patrolmen—Patrolling Surfaced Roads—Gang Maintenance—Gang Maintenance on Earth Roads—Gang Maintenance of Gravel and Macadam—Oil Storage—Gang Maintenance on Sheet Surfaces—Gang Maintenance on Brick and Cement Surfaces—Snow Removal—Snow Plows—Maintenance of Streets—Dust Suppression—Street Sprinkling—Cleaning—Sweeping—Flushing—Hand Sweeping—Cleaning Drainage Accessories—Snow Removal—Examples of Good Practice.

CHAPTER XXIII

ROAD MATERIAL TESTING 446

Methods of Proportioning Concrete Aggregates—Abrams' Tables of Proportions—Standard Sieves—Sieve Analysis of Sand or Fine Aggregate—Sieve Analysis of Broken Stone, Gravel, Pebbles, or Broken Slag—Tests for Determining the Amount of Clay and Silt in Gravel—Proposed Soundness Test for Coarse Aggregate—Test for Apparent Specific Gravity and Absorption of Stone or Other Coarse Material—Abrasion Test for Rock—Slump Test for Consistency of Concrete—Standard Methods of Test for Apparent Specific Gravity of Sand, Stone, and Slag Screenings, and other fine Nonbituminous Highway Materials—Standard Methods of Test for Toughness of Rock—Abrasion Test for Gravel—Tentative Method of

PAGE

Test for Organic Impurities in Sands for Concrete—Tests of Vitrified Paving Brick—Ductility of Bituminous Materials—Float Test for Bituminous Materials—Flash and Fire Points by Means of Open Cup—Penetration of Bituminous Materials—Loss on Heating of Oil and Asphaltic Compounds—Distillation of Bituminous Materials Suitable for Road Treatment—Softening Point of Bituminous Materials—Determination of Bitumen Soluble in Carbon Disulphide—Determination of Bitumen Insoluble in Paraffin Naphtha—Bitumen Insoluble in Carbon Tetrachloride—Specific Viscosity Determination—Method for Examination of Bituminous Mixtures.

GLOSSARY 488

INDEX 497

CONSTRUCTION OF ROADS AND PAVEMENTS

CHAPTER I

THE DEVELOPMENT OF HIGHWAY SYSTEMS

The construction of roads and pavements by any unit of organized government is brought about by the combined effect of many social, political, and economic influences. Public improvements, such as roads and pavements, involve the expenditure of great sums of money and, therefore, can be prosecuted only as rapidly as funds are made available. It is quite as important to understand how to foster an enlightened public opinion with reference to the subject as it is to know how to construct improvements of the requisite durability and general satisfactoriness.

Social Considerations.—A certain amount of social intercourse is a necessity and, in the rural communities, it is particularly salutary to the health and happiness of the people that reasonable social opportunities be provided. There is plenty of evidence in the records of sanitariums and asylums to show that isolation and the resulting loneliness have had a tendency to disturb the mental balance and undermine the health.

With the advent of the rural telephone, free mail delivery, the automobile, and parcels post, conditions of living in the rural communities are much improved, but none of these take the place of social gatherings. If the highways are well kept and comfortable to travel at all seasons of the year, it will do much to facilitate social life and the whole community will respond to the interchange of ideas and experiences.

Many of those who have secured a competence on the farm would prefer to continue living there were it not for the lack of social opportunities. They are usually the class of citizens who are most progressive and whose example is invaluable to their

neighbors on account of the advanced methods of farming they follow and their enlightened attitude toward all rural problems. Good highways, giving them free intercourse with their neighbors and with the towns, will do much to induce this class of citizens to stay on the farm, to the advantage of the commonwealth.

Educational Considerations.—Highway improvement has an important bearing on the educational opportunities of the children who live in the country. These children should have schools comparable to those available to the children who live in the towns and, indeed, the solution of the problem of insuring an adequate future supply of food to the nation depends upon the proper education of the children in the rural communities. Educators think that, in order to give suitable training in the country districts, group schools are a necessity, and the success of those schools depends upon there being serviceable roads throughout the district tributary to the schools.

Many institutes, farmers' clubs, and college extension activities have developed in recent years, which have a broad educational value, and all depend for success upon the facility with which people can assemble at some convenient place for instruction and discussion. They will do this only when roads are reasonably good.

Economic Considerations.—While the various social and educational aspects of the rural highway problem are of great importance, they are less so than the transportation phase. Highways should be considered primarily as links in the transportation system of a nation and it is vital that they be maintained in usable condition throughout the year. The roads are a part of the equipment needed for the transaction of business and any reasonable expenditure for road construction is justifiable as a matter of enlightened public policy.

Not infrequently, the system of farming and the whole rural business of a community have been transformed, due to the improvement of the highways, greatly to the benefit of the rural population and the market center of the district. The financial benefits derived have been many times the cost of the improvement of the highways.

The territory tributary to the larger cities (which is a source of supply for the more perishable food stuffs) is quite often cut off from its most logical market by the poor conditions of the highways. Such a condition causes a financial loss to both

producer and consumer which, in a few years, will aggregate a sum far in excess of the cost of any system of highway improvement that might be necessary.

Engineering Considerations.—The public highways of a commonwealth now comprise a great system of routes for transportation and should be constructed and administered as such. In sparsely settled districts, they serve for the necessary intercourse between farm and market center, and are vital to the life of the people although the traffic is light. In such communities insufficient funds are available for the construction of other than the cheapest roads, and those who use the highways for business or pleasure must accommodate themselves to the varying conditions of the highways. The important consideration in such a community is not the possibility of building roads designed for low tractive resistance and long life, but is rather to secure the most durable surfaces that can be constructed with the meager funds obtainable. When small sums only are available, it becomes the more important to study carefully all of the economies possible, and to make extraordinary use of the materials and equipment at hand. Such a study may result in sand-clay or light gravel roads being built, as has been the case in many sections of the United States, or it may result in the development of a new maintenance device or method of construction.

The more thickly settled the district, the more burdened the transportation system becomes. In those sections of the country which are so densely populated that there is a succession of towns and cities, the public highways are much-used arteries of commerce. The public highways, in such instances, are utilized for both business and pleasure by great numbers of citizens, and assume an importance that rapidly increases each year.

In these populous districts large sums of money may be had for highway improvement and, moreover, the types of roads that would suffice for sparsely settled country are totally inadequate. The problem then becomes one of providing roads of great durability even though the cost is high. The greater the cost of roads, the greater the skill that should be exercised in the selection of the type and the supervision of the construction.

Since the traffic on the public highways is so diversified in character and consists of so many small units under separate ownership, the tremendous handicap and loss due to poor roads is but vaguely recognized. It is apparent, nevertheless, that the

amount of energy required to move a load over a public highway is of great significance. If but a few vehicles use the road each day the cost for power may be unimportant economically, although it may be a serious matter to those who use the road. If, however, the number of vehicles that pass over the road is large, then the amount of energy expended is an important consideration.

In general, hard-surfaced roads are of lower tractive resistance than earth roads, but the aggregate energy saving on a hard-surfaced road over an earth road will be small or large, depending upon the amount of traffic that uses the road. The fact that it costs less to haul a load on good roads than on bad roads is well established. Just how much less it costs is not of first importance.

Highway improvement is very often brought about by a desire for greater comfort and convenience, rather than from a desire to save on the cost of hauling. People readily sense increased comfort of travel, freedom from dust or mud, and facility in getting about, but they do not have tangible evidence of lowered costs unless they keep accurate records of expenditures, which few people do.

ADMINISTRATION OF RURAL HIGHWAYS

The highways of most progressive nations are grouped into systems for the purpose of administration, although the selection of the particular highways that constitute each system has generally been a slow process. The nucleus of the system was first selected, and additions and eliminations followed, year after year, until those in authority believe the system to be perfected. In the United States the grouping of highways into systems has been under way for 30 years or more. In some areas, the process is substantially complete, while in others it is in active progress and will require many years for completion. The general principle of classification has been generally accepted in all states, and either a tentative or a final classification of highways has been made.

The classification of highways has not been on a basis whereby it is possible to specify a single type or design of roadway surface for each system, and probably the traffic on any system will never be sufficiently uniform to permit that. Yet it is recognized that for each system there is some minimum of durability below which it is inadvisable to go in selecting types of roadway surfaces.

The rural highways of the United States may be considered to fall into four groups, or systems. These groups are known by various names in the several states where they have been officially set out, but regardless of whether official grouping has taken place or not, the systems are quite generally recognized, not only officially, but also by the public.

United States Highways.—The group known as United States Highways was selected by a joint board on Interstate Highways, appointed by the Secretary of Agriculture of the United States, Mar. 2, 1925, which was made up of representatives of the state highway departments and the federal Bureau of Public Roads. These highways are the important interstate routes and, for the most part, had already been selected from the trunk highway systems of the several states for improvement with federal aid.

The purpose of establishing the federal highway system was to insure the gradual development of a truly national network of suitably surfaced highways through the concentration of effort and funds, especially federal aid. These roads are the routes for long distance travel, and at the same time are much-used parts of the state road systems. They are numbered and provided with guide and warning signs of uniform design throughout, regardless of state lines.

The federal highways in each state remain under the jurisdiction of the state, and all construction and maintenance work on them is carried out by the state authorities, subject to general regulations and supervision by the federal government. The cost of construction is met jointly by the state and the federal government.

State Trunk Highways.—The state highways are the transstate and intercounty roads that form the main routes for the intercity travel in the state. These roads are variously defined and named, and were selected by methods devised by the legislatures of the respective states. In general, they constitute from 6 to 10 per cent of the total mileage of a state, and include such United States highways as traverse the state.

In some portions of the United States, the state road systems have existed for a number of years and little change is made in the layout from year to year. Minor relocations and occasional slight alterations are made in the routes, but the system as a whole is pretty well fixed. In other areas a preliminary selection

of the state roads has been made, but additions, eliminations, and general revisions will be continued for a number of years.

The state road system is assumed to connect all the cities of such size or importance as to be the source or destination of travel from a distance, and to constitute convenient routes for travel throughout the state. The system should afford access to recreational areas, places of scenic and historical interest, and regions of agricultural or industrial development.

State roads are improved, maintained, and managed (except for policing) by the state highway departments. The parts of the state system that are also United States Highways are managed by the state but certain standards of construction and maintenance that are set up by the federal government must be observed by the state.

Main Market Roads.—The main market roads supplement the state roads in providing a connection between farming areas and market centers. Thus, there is a group of such roads converging on each market town and connecting the villages with their neighboring cities. It is not easy to define a road of this class because conditions differ so much in various parts of the state and in various states. Generally speaking, whenever a road carries some volume of traffic through more than one local road district, it belongs in either the market-road class or the state-road system. If not sufficiently important for the state-road system, it is placed in the market-road group.

This class of highway is called the county road in some instances, the main market road in others, and in many states has no official designation. The group exists in every state and ought to be set out in the administrative system and provision made for its proper development and maintenance. The management of these roads devolves upon the county or district rather than upon the state highway authorities.

Local Roads.—The local-road system is made up of the roads that do not fall in any of the other groups. While the actual right-of-way of these roads may extend entirely across a county, or even several counties, the use is such that there is little continuous travel for distances greater than a few miles. Roads of this class connect the individual farms with the main market system or the state system. Local roads are not officially set out as a distinct system in the laws of most states, but whether officially recognized or not, the system is under the jurisdiction of the highway officials of the township or subdistrict.

There is good reason to believe that local roads could better be managed by the officials who are responsible for the main market or county roads, thus entirely eliminating the township, or subdistrict, as a road-building agency.

Urban Highways. Streets.—Highways lying within the corporate limits of incorporated towns and chartered cities are under the jurisdiction of the municipal government, and parts of the street system form links in the general transportation facilities of the state. While attempts are made to provide by-pass roads around the larger cities, this has been accomplished only to a limited extent, and through traffic must use certain streets of the cities. A great deal of the highway traffic has its origin or destination, or both, in some city or town and therefore the city street must be used for a part of the journey, even though it is possible to pass around intermediate towns on the route.

Correlation.—There has been some correlation of effort on the part of those in authority over the several rural highway systems, and a somewhat harmonious development of each group of roads. There has been little effort to improve adequately the streets that form links in the rural highway systems, and the poor pavements in the smaller cities and towns have been the source of considerable annoyance to traffic. Increasing attention is being directed to this situation and a solution will doubtless be forthcoming in due time.

Significance of Classification of Highways.—The several systems of highways that have been described should not be considered separate entities, each to be administered independently of, and without reference to, the program adopted for the others. When that has been the practice, it has usually been contrary to the public interest. Classification should be looked upon as an administrative device made necessary by the nature of the problem presented in the improvement of a vast and far-flung network of highways. It is true that certain units of traffic may use one or the other of the road systems exclusively, but there is a great volume of traffic that uses any one of the systems whenever it proves convenient to do so. Classification is not, therefore, based on the notion that for each system of highways there exists a traffic that is peculiarly adapted to that system, with vehicles of appropriate design and schedules that may be varied according to the condition of the highways in the system for which they were prepared.

In railroad practice, main line schedules and motive power may be, and usually are, different from those of branch lines, although ordinary freight and passenger cars are operated on all parts of the system. But highway traffic is not adapted to the road system to any such extent as is rail traffic. Some types of highway transport, such as busses and the heavier trucks, do not attempt to use regularly the secondary road systems, but privately owned automobiles and trucks use any, or all, of the systems as they find occasion.

It would be more appropriate to consider the several road systems as *divisions* of the highway system of the nation, because there is an interrelationship in function and an obligation to maintain each part in condition to accommodate properly its share of the traffic. A certain amount of correlation of effort on the part of those in authority over each group is essential to the achievement of the harmonious improvement of each division of the highway system. Considerable progress is being made in securing the cooperation of state and federal authorities on projects of mutual interest but the local county and township boards quite generally drift along without regard to what any other official body is doing.

HIGHWAY AUTHORITIES

It has been pointed out that several divisions of the highway system are recognized in the United States. If the responsibility of each group of officials is clearly fixed by law, it has a tendency to cause officials to be faithful in the performance of their duties because an accounting is likely to be demanded at any time. Laws are slowly being brought into harmony with the theory of clearly fixed authority and responsibility.

Federal Authority.—The authority of the federal government in highway affairs exists by virtue of the contribution of federal funds to the states for road improvement. Because of limitations imposed by the Constitution of the United States, the federal government cannot enter a state to build or maintain roads and it does not attempt to do so. It does contribute a part of the cost of certain classes of roads, which entails administrative participation of the federal government in highway affairs. This is exercised by the Secretary of Agriculture, who functions through the Chief of the Bureau of Public Roads. Projects for which federal aid is requested must be approved by the Secretary of

Agriculture, and the plans, specifications, contracts, and construction must meet the standards set up by him, through the Bureau of Public Roads, before federal funds will be paid to the states.

While the federal government has contributed many millions of dollars to the states in the form of federal aid for roads, its most important contribution has been insistence upon high standards of engineering, and technical supervision of construction by the state highway departments. In this way the federal government has performed a service the value of which cannot possibly be overestimated.

State Authority.—The state road systems are managed by state highway departments, which derive their authority from the legislatures of their respective states. The state highway departments take several forms, but, in general, they consist of an executive body in the form of a commission, advisory board, or a single commissioner; an administrative organization under a commissioner, secretary or chief engineer; and an engineering organization. The executive body is generally appointed by the governor of the state and the remainder of the organization is employed by the executive body, either through a Civil Service system, a personnel division in the highway department, or by permitting responsible division chiefs to employ their subordinates.

The state highway departments have jurisdiction over the construction and maintenance of the state road system, and may utilize federal aid up to the limit of the state allotment. These departments may purchase supplies, equipment and materials, exercise the power of eminent domain for the acquisition of right-of-way, and in general do all things required to build and maintain highways, including all of the elements thereof, such as culverts and bridges, guard fences, snow fences, tile lines, drainage ditches, guide signs, and roadway surfaces.

In those instances where federal aid is employed, the location of the project and all the details of design and construction must be in accordance with the standards established by the federal government.

In many states the highway departments are permitted to grant state aid to counties, or townships, for the construction of approved secondary roads.

County or District Authority.—Roads set out as county, or district, highways are managed by an elective board of super-

visors, or commissioners, whose powers and duties are established by the state legislatures. These boards generally conduct all of the business of the county, or district, besides looking after the road system. Thus, they are responsible for the maintenance of the seat of county government, fix taxes, prosecute drainage projects, care for the poor, and perform all of the multifarious duties of county government. As a rule these boards appoint a county superintendent or engineer to take charge of the road work of the county, and he in turn employs such assistants as may be required. In some populous counties special boards of road commissioners are elected to manage the road system and these have no other official duties.

County boards are authorized to accept state aid for road construction in certain instances, and when they do so the project must be approved by the state highway commission and all work in connection with any construction thereon must be in accordance with the standards fixed by the state. In some states, all county road and bridge work must be of a standard fixed by the state highway department and all contracts be approved by the state, even though no state funds are given to the work. This is by way of securing some degree of correlation between the work on the state and the county road systems.

Township Authority.—The local roads are not legally defined in all the states, being in most instances the left-overs after the other systems have been selected. They are generally managed by the officials of the township, or subdistrict, and these in turn divide the system into units each of which is assigned to the care of a designated commissioner, or trustee, who employs road gangs and patrolmen to do the actual road work. Bridge and culvert work, and road surfacing may be performed by contracts awarded on the basis of competitive bids, but as a rule the townships do not employ engineers and must therefore engage consultants for projects requiring plans and specifications. A few states empower the county authorities to build all the culverts and bridges on the local road system. In other states, the townships may obtain aid from the county for the construction of roads and bridges when the cost thereof is beyond the financial capacity of the township.

There is a growing feeling that the township is too small a unit of road administration under modern traffic conditions, and that the duties might better be consolidated with those already

imposed on the county authorities. This proposal has scarcely progressed beyond the discussion stage, and many years of consideration will likely ensue before it becomes effective, if it ever does. Certainly the proposal offers possibilities in the direction of a better correlation of work on the two large divisions of the road system.

EVOLUTION OF HIGHWAY FINANCE

At the beginning of the present period of expansion of the highway construction programs, highway finance was a simple matter. All of the work under each administrative board was financed from the income from general taxation on the property in that political unit. That is, township or subdistrict work was financed by township or subdistrict taxes, county or district work by county or district taxes, and state work by state taxes appropriated periodically by the state legislatures. There was no federal work except that the educational and investigational activities of the Office of Public Roads of the United States Department of Agriculture were financed from congressional appropriations to the Department.

The counties, townships, districts, and subdistricts were permitted to issue bonds under certain restrictions and in the years following 1890 did issue a great many millions of dollars of such bonds, the proceeds being used for macadam, gravel, or other intermediate-type roadway surfaces. Since bonds are generally issued in anticipation of some increase in the normal income, it naturally followed that taxes had to be increased to meet the bond payments.

The appropriations to the state road work increased until it became apparent that state taxes would have to be increased to meet the situation. In some instances state bonds had been issued, which added to the burden. The resistance to increased property taxes was so insistent that some other means had to be devised to secure the additional revenue, and out of the necessities of the situation the automobile license fee was born. This was gradually increased in rate until the limit of endurance was reached, but even then the revenue was insufficient and so the gasoline tax was introduced. This began at the rate of 1 or 2 cts. per gallon and has been increased 1 ct. at a time until it now amounts to as much as 5 cts. per gallon in some states. The revenue from vehicle license fees and the gasoline tax was at first

devoted entirely to state road work and even then there was insufficient money to meet the demand for better roads. Moreover the states were not completing the transstate routes as rapidly as the people wanted them. It seemed impossible to achieve a connected system of interstate roads except by the introduction of federal money to stimulate that particular part of the work. The present system of federal aid grew out of this situation.

When the counties, cities, and other subordinate units of highway administration began to realize how much money the states were spending, they sought an increase in funds for the secondary roads. This finally took the form of a distribution of part of the gasoline tax and motor-vehicle license fees to these units.

The cities had, from the beginning, depended upon special assessments and general taxation for funds for street improvements; special assessment having furnished the most of the funds for this purpose. Ordinary maintenance has been paid for out of general taxation, and reconstruction costs have been paid by reassessing the benefited property; by general taxation; by special taxation; and, in a few instances, by imposing a vehicle tax payable to the municipality.

THEORY OF HIGHWAY FINANCE

The variables to be considered in devising a system of highway finance are so numerous that an attempt to evaluate each leads almost to bewilderment, and the possibility of arriving at any rational solution seems hopeless. But it is imperative that highway finance be placed on a sound basis and the longer that is delayed the greater will be the difficulties when economic pressure forces action. The problem resolves itself into the employment of a few acceptable forms of taxation, most of which are already used by a number of states, but the application of these principles is by no means a simple matter. A brief discussion may serve at least to indicate the nature of the problem.

Basic Principles.—The imposition of a highway tax of any kind should be based on a consideration of the following factors:

1. The magnitude, distribution, and nature of the benefits that accrue from road improvement.
2. The equity of the system among the tax-paying units affected.
3. The ability of the tax-paying units to meet the impost without being subjected to economic distress.

Benefits.—Three classes of benefits are recognized as growing out of road improvement. While these overlap to some extent, they may be considered as distinct so far as the theory is concerned.

General Benefits.—This is a somewhat inadequate designation for those benefits that are reflected in the social, commercial, and educational stimulation afforded by an increase in the facility with which people and goods may be transported. Such benefits first manifest themselves locally, but flow out along the lines of commerce and combine with the effects from other local sources to become of tremendous national importance. These benefits are reached, in a measure, by general property taxes.

Special Benefits to Land.—Highway improvement may, and frequently does, confer a special benefit to lands lying within a zone adjacent to the improvement. The eventuation of such a benefit in a specific instance depends upon the nature of the highway improvement and upon the capacity of the land to respond to the stimulation thereof. Benefits of this type cannot be measured by a general land tax but may be reached by special assessments.

Special Benefits to Traffic.—The benefits to traffic are of two types. The one is that which results from the fact that improved roads exist in an area, ready to serve the traffic that chooses to use any particular improved highway. The other is the benefit, in the form of lowered operating costs and business advantages, that accrues to those who actually use a particular improved highway. These benefits are the justification for the motor-vehicle license fee and the fuel tax.

Equity.—Having decided that a certain class of benefits serves as justification for a particular form of highway tax, it remains to adjust the method of application of the tax so that imposts will be equitable. In effect, one must answer this question in the affirmative before approving any system of highway taxation: Do all tax-paying units contribute on substantially the same basis of assumed rate, or intensity, of benefit? Generally the problem presents itself in some such form as this: Is the gas tax equally fair to busses and to trucks? Or; Is the basis for assessing the vehicle license fee equitable as among vehicles of various sizes, prices, and classes?

Ability to Pay.—It seems to be recognized that, in the formulation of taxation schemes for raising revenue for highway

improvement, as in schemes for other forms of taxation, it is proper to take account of relative ability to pay on the part of tax-paying units, whether they are individuals or corporate entities. This is well exemplified by the graduated income tax and, in highway taxation in some states, by the portion of the motor-vehicle license fee which is based on the list price of the vehicle. Obviously, any such plan must be equitable among units of like ability to pay so far as it is humanly possible to achieve that end.

FORMS OF HIGHWAY REVENUE

While it is fairly easy to state the principles of taxation that should govern in obtaining revenue for highway improvement, the application thereof is by no means simple. Especially is it true that in seeking methods for increasing the income of highway departments to meet the needs of expanding construction programs, there will be great reluctance to employ some of the methods that seem to be indicated by an application of the principles involved.

Revenues Based on General Benefits.—General benefits are intangible and illusive. They are but vaguely understood and wholly unappreciated by the public. They shift about from area to area with changing economic conditions and the state of highway development. The only way they can be reached is by general taxation. But if general taxation in any area results primarily in taxation of real property, a great mass of value escapes taxation, and too great a part of the burden is thrown on real property. General taxation spread over small political units, such as the county or subdivisions thereof, does not achieve the desired result because concentrations of wealth in the cities very largely escape. Taxation spread over the state is satisfactory, so far as distribution is concerned but may place too heavy a burden on real property. Where state revenues are obtained from income, corporation, inheritance, and similar taxes, as well as from property taxes, state taxes for highway improvement reach the recipients of general benefits. If the state has an up-to-date system of assessment of property and a modern tax system, a state road tax is equitable, is in accordance with benefits and ability to pay, and may be justified on the basis of general benefits.

In some states the vehicle license fee is assessed in lieu of any other tax on the vehicle, that is, the vehicle is not assessed for general taxation. This is, in effect, levying a general state tax for road improvements, but it is paid by one class of citizens only—those who own vehicles subject to the law.

General benefits are of more than state-wide import and therefore justify the application of federal funds to highway improvement. These funds are obtained from forms of taxation that reach tax-paying units that are peculiarly affected by general benefits from highway improvement, because the tax-paying ability of these units fluctuates with the general prosperity of the nation.[1]

It is conceded that land should contribute to road funds, because the owners of the land participate in any general benefits that follow road improvement. It is not readily appreciated that road improvement remote from a given parcel of land has any influence on the prosperity of the owner of that land, but this is known to be the case. The land should therefore contribute its part toward funds based on general benefits, and a general tax is the only means of securing such a contribution.

Revenues Based on Special Benefits to Land.—Road improvement in the immediate vicinity of a parcel of land may confer a direct and measurable benefit on that land. This benefit may be so small that it is not worthwhile to try to reach it through taxation, or it may be so great as to increase the actual sale value of the land very materially. In this event the benefit should be the basis of highway revenue, which can be equitably obtained only through the application of special assessments. These must be made on a basis of the exact conditions surrounding the particular project involved. In some instances, this special benefit can best be reached through the application of the process known as "excess condemnation." The legality of this method is under a cloud at present and it is unconstitutional in many states. It does deserve serious consideration in connection with certain types of highway improvements.

The benefit received by traffic, in the form of lowered cost of operation and greater mobility, that follows road improvement, is justification for imposing upon traffic a tax that is proportional to the extent that each vehicle uses the highway. The prospec-

[1] "Who Pays Uncle Sam's Bills?" *American Highways*, Vol. 4, No. 4, October, 1925, p. 1.

tive benefit to traffic that arises out of the fact that improved highways have been provided, ready for use when desired, is justification for a readiness-to-serve type of tax to be paid on the same basis by all vehicles, regardless of the extent to which the roads will actually be used by the vehicle.

The readiness-to-serve tax should be based on the weight of vehicle for which provision had to be made, and to the cost of the vehicle, if it is desired to vary this charge with ability to pay.

The use tax should be in a form that will be strictly proportional to the use of the road, that is, to the miles of travel and the weight carried.

The gasoline tax is a satisfactory means of securing funds in proportion to road use so far as automobiles are concerned. It is in accordance with benefits and equitable as between individuals. It does no violence to the theory that ability to pay may be considered in fixing a tax. It is not equitable as between commercial vehicles and automobiles, although the disparity is small, except that the heavier commercial vehicles (say those above 2-tons capacity or 4-tons gross weight) are favored rather markedly. For the heavier commercial vehicles the gasoline tax should be supplemented by some form of mileage tax. In the case of common carrier vehicles the gross profits tax might be substituted for the mileage tax.

Summary.—There is reason to doubt the wisdom of thinking of road improvements in terms of construction operations and maintenance operations when dealing with financial problems. These two types of activity combine to constitute what might be termed highway maintenance, using the term *maintenance* in its broader meaning. If that interpretation is used, the cost of maintenance includes all expenditures required to keep the roadway in suitable condition for its traffic. This total cost should be met with funds obtained from the following sources:

1. General state and county taxes levied on the basis of assumed general benefits to the commonwealth. The present township taxes should be consolidated with the county taxes and supplemented by state funds, to be expended according to the needs of traffic, on all parts of the local highway system.

2. Federal funds allotted as at present but in greatly increased amounts. These funds are obtained by methods of taxation that more nearly than any other tap the accumulations of wealth that have resulted from the general benefits due to internal

improvements in the country. These taxes are equitable and to a marked degree comply with the principle of ability to pay.

3. Vehicle license fees; mileage, or gross profits on operation taxes; and the use tax in the form of the gasoline tax.

4. Special assessments or income from excess condemnation. Unimportant in the aggregate amount but necessary in connection with some types of improvements.

Bonds.—The anticipation of future revenues through the issuance of bonds is justifiable for any capital expenditure of an enduring nature that promises to yield returns commensurate with the interest cost incidental to the issuance of bonds.

It seems quite clear that for many years it will be necessary for states to continue to issue bonds to secure funds for investment in roads. If the administration is efficient, this method of providing funds is equitable, proper, and economical. It is merely the adaptation of good business methods to a very urgent public enterprise. Obviously, the proceeds of the sale of bonds should not be used for routine repairs on road surfaces. But the bond method of financing is certain to be the key to the problem of the working out of the present inadequacies of the highway systems of some of the states. In most cases, the use of current funds will not permit sufficiently rapid progress to catch up with the needs of traffic, and, meanwhile, routine repair costs will absorb a totally disproportionate share of the income.

Summary.—The sources of revenue available to the several political units in the United States at the present time may be summarized as follows:

A. The State:

1. Vehicle license fees.
2. Gasoline tax.
3. Special assessments (to a very limited extent).
4. Federal aid.
5. General state taxes.

B. The County or District:

1. General county taxes.
2. Allotments of the gasoline tax.
3. Allotments of the state vehicle license fee.
4. State aid for special projects.
5. Special road taxes for limited periods (usually levied to amortize bond issues).
6. Special assessments.

C. The Township or Subdistrict:

1. General township taxes.
2. Allotments of the gasoline tax.
3. Special county grants for limited projects.
4. Special taxes for limited periods (usually levied to amortize bond issues).

D. Municipalities:

1. Special assessments on benefited property.
2. General taxes.
3. Special taxes (usually anticipated by bond issues).
4. Vehicle taxes (in addition to the state license fee).
5. Allotments of the state gasoline tax (in a few states).
6. State aid for streets that are part of state road system (usually granted only to smaller cities).

E. Federal Bureau of Public Roads:

1. Appropriations made by Congress to the United States Department of Agriculture.
2. Congressional appropriations for federal aid for roads in the states.

ADMINISTRATION OF STREET PAVING

Pavements are as necessary for a city of any commercial importance as are railroads and it is taken as a matter of course that all except the least important residence streets in outlying districts will be paved. Transportation demands, convenience, cleanliness, and appearance are all potent factors in creating a desire for improved streets. Many streets are paved upon which the traffic is so small in volume that transportation needs alone would not justify it, but other considerations are such that the residents are willing to pay for the improvement.

Street paving is administered in a number of different ways in American cities but, in general, is under the jurisdiction of an elective body which delegates its authority to a subordinate department.

Administrative Systems.—Where the affairs of a city are administered by a city council or board of aldermen, the paving is supervised by one or the other of the following organizations:

1. A committee of aldermen, which is known as the Committee on Streets and Alleys, the Board of Local Improvements, or by some similar designation. Final action on contracts is generally required of the entire board.

2. A special Board of Public Works, which is either appointed by the mayor or is elected. Such boards generally have final authority in paving matters.

When the city is organized with the commission form of government, one of the commissioners usually has charge of public improvements, including paving, and final action on contracts is by the commission.

Cities that are organized under the city-manager plan usually have a department for handling the street work which is subordinate to the city manager. The contracts are subject to approval of the city manager and the advisory board.

Street repairs and street cleaning are commonly administered by the same organization that is responsible for the construction of new pavements, but the street cleaning is generally handled through a special bureau.

The laws relating to street improvements have developed out of the necessity of providing some representative body with authority actually to force improvements in areas that really require pavements. Usually, the constituted authority may override opposition on the part of property owners who object to the improvements, if that becomes necessary. This power is rarely abused, because most boards of aldermen find it inexpedient to force improvements except where real need exists.

In all cases, the legal procedure incident to street improvement is definitely set forth in the statutes. Rigid adherence to the prescribed formalities is a prerequisite to levying a special assessment to pay for the work.

The weakness in most street-improvement procedure lies in the provision for the selection of the type of pavement. In a matter so clearly requiring specialized technical training, the selection should be made by an engineer who is entirely familiar with the requirements of the location and the suitability of available types of construction.

Systems of Financing.—The methods of securing funds for paying for street paving, like those employed for rural highways, have evolved out of the necessities of the case. It has been imperative that the work be done and the easiest way to secure funds was through special assessments against abutting and adjacent property, which method has been very generally employed for the initial pavement, and quite widely for subsequent renewals of that pavement.

There is a growing conviction among municipal authorities that in many locations a part of the cost of renewals should be paid from the general funds of the city. A number of cities now

have various methods of supplementing property assessments, especially for repaving. Proceeds of a general property tax constitute the most common source of funds for this purpose, but the wheel tax is employed to a limited extent.

Payment for paving is by means of paving certificates of paving bonds which are issued as soon as the pavement is accepted. These evidences of indebtedness are payable in annual installments for a period of years and thus the property owner is given from 5 to 10 years for paying for the paving.

The variation in practice is indicated by the following excerpt:

New Paving:[1]

In 62 per cent of these cities the property pays all.
In 6 per cent the property pays 50 per cent.
In 10 per cent the property pays more than 50 per cent and less than 60 per cent, except in one city, where the property pays 30 per cent.
In 22 per cent the city pays all.

Repaving:

In 42 per cent of these cities the property pays all.
In 10 per cent the property pays 50 per cent.
In 8 per cent the property pays between 50 and 100 per cent.
In 40 per cent the city pays all.

Approximately 25 per cent of the cities pay the major part of the original paving, while 40 per cent of the cities do the major part of repaving.

SPECIAL ASSESSMENTS FOR PAVEMENTS

The cost of constructing pavements on city streets, therefore, is paid in whole or in part from a fund raised by a special assessment on the property abutting or adjacent to the street that is paved. Property that has some frontage on the paved street is known as "abutting property" and property having no frontage on the paved street, but which lies in the block along which the pavement is laid, is known as "adjacent property." Usually, the law specifies the limit of area adjacent to the paved street within which it is permissible to levy special assessments for paving.

Many systems of making special assessments have been devised, all of which seek by some mathematical means to spread the assessment equitably to all parcels of land involved, which

[1] Report of the Municipal Committee of the Cleveland Chamber of Commerce.

necessarily includes the assumption that all parcels can bear assessment. This may not be true in some instances, and, after the assessment has been spread by some appropriate system, the whole plat is studied in the light of the character and value of the several properties, and adjustments are made where the assessment seems inequitable.

Items of Cost Assessed.—Most of the state laws permit the addition of the cost of all incidental work to the cost of the pavement and the total thus obtained, or some predetermined part thereof, to be assessed against the property within the statutory distance of the improvement. The cost of storm inlet changes, manhole changes, crossing plates, legal expenses, and sometimes engineering and inspection costs, are considered to be essential parts of the cost of the improvement.

In computing the total amount to be assessed for the pavement on a street, it is customary to compute the cost of each section of substantially identical construction, whether it be a part of a block or many blocks. If the pavement is of the same design and dimensions throughout, differences in the number of items of special or incidental work in the various blocks need not be considered to constitute a change in type. Whether the cost of the part of the work at street intersections is to be included, depends upon local laws or customs. A part of the total cost may be paid from general or special funds and the remainder specially assessed or the total may be assessed.

In theory, the special assessment is spread on the basis of the special benefits conferred by the street improvement. But the size and shape of the parcels of land, the nature of the business conducted thereon, the area of the block, and many minor physical features of the street and alley layout are involved in the determination of special benefits, and the equitable assessment of the cost of street improvements is not susceptible of reduction to formula. Nevertheless, various formal methods are employed for spreading assessments and these serve admirably to distribute equitably the rate of benefit after the basis of distribution has been determined upon. In every instance the final assessment is arrived at by a judicious review and modification of the results of a mathematical distribution of benefits.

The distribution of benefits is computed in various ways, depending partly upon the laws relating thereto, and partly upon the opinion of the assessing officer, as to what constitutes a

suitable basis for the particular project. In every case the purpose is to assess the costs in accordance with the benefits and with equity to the various properties involved.

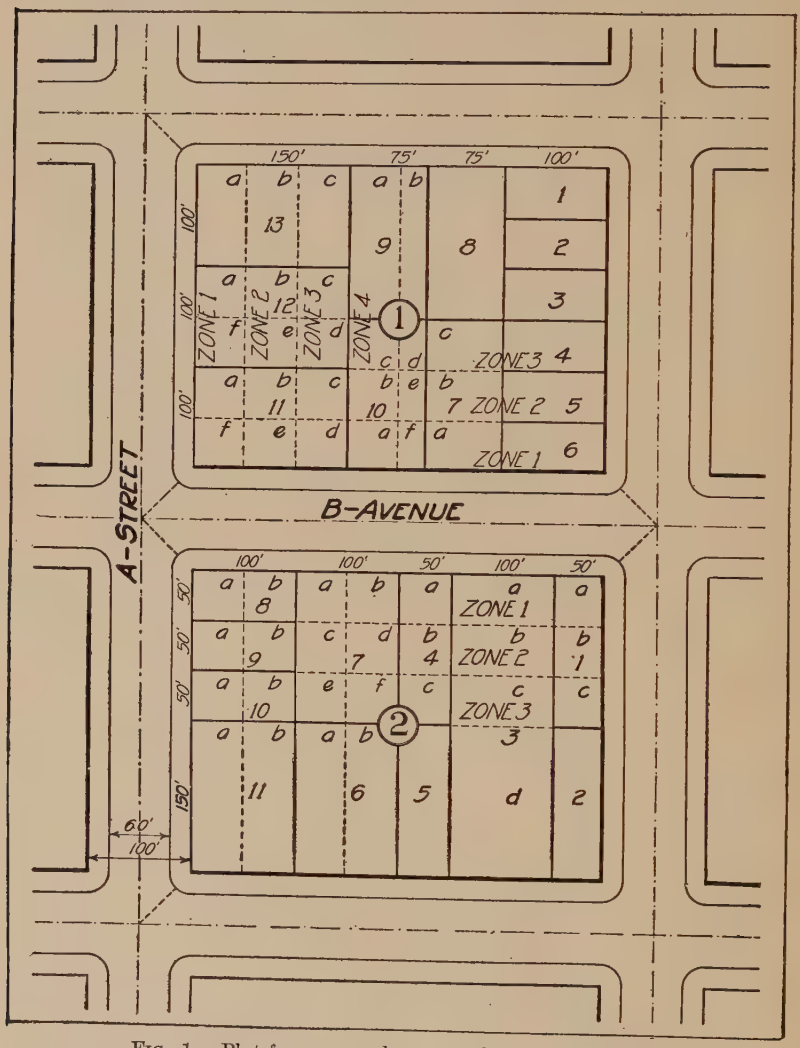

Fig. 1.—Plat for zone and area method of assessment.

Front Foot Rule for Assessments.—In many cities, only the abutting property is assessed and the cost is spread in proportion to the length of frontage of each lot or parcel of land on the paved street. This rule is, of course, simple of application but does

TABLE I.—ILLUSTRATING THE ZONE AND AREA METHOD OF ASSESSMENT

Assessments for B Avenue

Block	Lot	Parcel	Area, sq. ft.	Rate	Assessment	Remarks
			Zone 1			
1	11	f	2,500	0.179293	$ 448.23	B Avenue Rates: Zone 1—65 per cent. Zone 2—25 per cent. Zone 3—10 per cent.
1	10	a	2,500	.....	448.23	
1	7	a	3,750	.....	672.34	
1	6	..	5,000	.....	896.47	
2	7	a	2,500	.....	448.23	
2	3	a	5,000	.....	896.47	
			Zone 2			
1	11	a	2,500	0.068960	172.40	
1	10	b	2,500	.....	172.40	
1	7	b	3,750	0.068960	258.60	
1	5	..	5,000	.....	344.80	
2	9	a	2,500	.....	172.40	
2	3	b	5,000	.....	344.80	
			Zone 3			
1	12	f	2,500	0.027584	68.96	
1	10	d	1,250	.....	34.47	
1	7	c	3,750	.....	103.43	
1	4	..	5,000	.....	137.91	
2	3	c	5,000	.....	137.92	

Assessment for A Street

			Zone 1			
1	13	a	5,000	0.145003	$ 725.02	A Street Rate: Zone 1—50 per cent. Zone 2—25 per cent. Zone 3—15 per cent. Zone 4—10 per cent.
1	12	a	2,500	0.145003	362.51	
2	9	a	2,500	.....	362.51	
2	11	a	7,500	0.145003	1,087.52	
			Zone 2			
1	13	b	5,000	0.072501	362.51	
2	9	b	2,500	.....	181.25	
2	11	b	7,500	0.072501	543.76	

TABLE I.—ILLUSTRATING THE ZONE AND AREA METHOD OF ASSESSMENT —Continued

Assessment for A Street

Block	Lot	Parcel	Area, sq. ft.	Rate	Assessment	Remarks
			Zone 3			
1	13	c	5,000	0.043500	217.51	
1	12	d	2,500	.....	108.75	
2	7	c	2,500	.....	108.75	
2	6	a	7,500	0.043500	326.25	
			Zone 4			
1	9	a	7,500	0.02900	217.51	
1	10	b	2,500	.....	72.50	
2	6	b	7,500	0.02900	217.51	

not take into account possible variation in the depth of the several lots which would be desirable if the lots were not of about equal depth.

Area Method of Assessment.—Another simple method is to spread the assessment according to the area of each lot or parcel of land. This takes account of the differences in size of the lots but does not compensate for differences in frontage on the improved street, which would be desirable if the lots were not of about the same width throughout the area assessed.

Zone-and-area Method.—In this method, the area to be assessed is divided into equal zones, each zone extending the length of the pavement for which the assessment is being prepared. A rate of assessment is then determined for each zone. In the example given herein (Fig. 1) the area to be assessed for the improvement of *A* street is divided into four zones, and the rates for the several zones are 50, 25, 15, and 10 per cent, respectively. This means that the zone nearest the street bears 50 per cent of the total cost of the improvement, which is distributed to the various parcels of land in the zone in proportion to their respective areas. The area to be assessed for the improvement of *B* Avenue is divided into three zones, bearing respectively 65, 25, and 10 per cent of total cost. Table I shows in outline the method of spreading the assessment.

This method is applicable to blocks that are divided in a regular manner into rectangular areas of substantially equal depth measured perpendicularly to the street, or into areas that are even multiples of some common unit depth.

The area to be assessed may be divided into any desired number of zones and the respective rates on the zones fixed in accordance with the judgment of the responsible official body.

Benefit Factor Method.—The zone-and-area method of spreading assessments is based on the theory, which is also accepted in real estate valuation, that benefits from street improvements decrease as some power greater than unity of the distance from the street. Some authorities consider the benefits to decrease

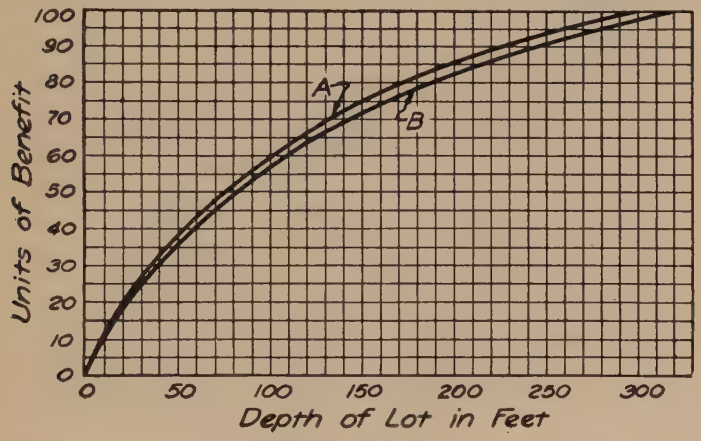

FIG. 2.

as the square of the distance and some as the cube of the distance. In the zone method, the benefits are assumed to be constant in each zone, which is obviously not true, but the lot layout is often of such a character that no injustice results from the assumption. In other instances, the lots and parcels of land are laid out in such a way that more equitable results are obtained by taking account of the rate of diminishing benefits as the distance from the improvement increases. This is accomplished by determining the benefit for each parcel of land from a benefit curve drawn to represent the assessor's opinion of the rate of diminishing benefits for the improvement for which he spreads the assessment.

There is shown in Fig. 2, Curve *A*, a benefit curve for an assessment area 300 ft. wide (block 600 ft. long), platted on the

assumption that the benefits diminish 50 per cent in the first one-fourth of the distance, 25 per cent in the second one-fourth of the distance, and 15 per cent in the third one-fourth of the distance. Curves showing other rates of diminishing benefits and for other widths of assessment area may be prepared to

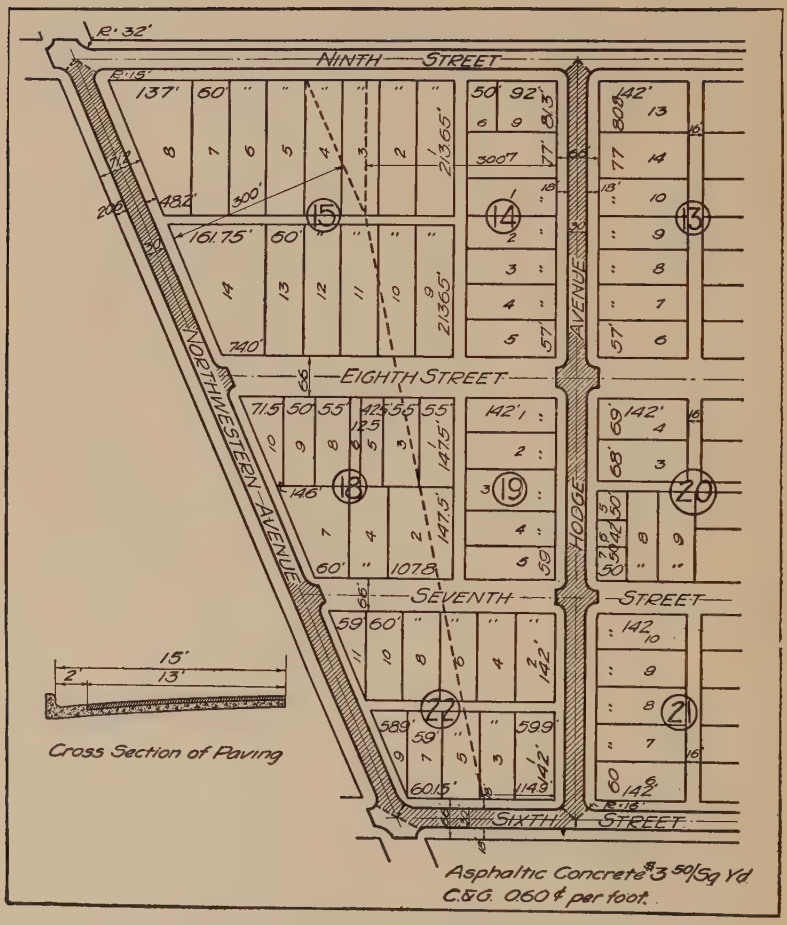

FIG. 3.—Plat for assessment by benefit factor method.

comply with existing conditions and the curve shown herein is illustrative only, although it has been used for many special assessments. Figure 3 is the plat for an assessment district and Table II shows the method of applying the curve to the assessment of the cost of the pavement on Hodge Avenue. A some-

TABLE II.—ASSESSMENT FOR HODGE AVENUE

Lot	Block	Rate	Length	Unit of benefit (3) × (4)	Unit assessment	Assessment (5) × (6)
1	2	3	4	5	6	7
6	13	72.5	57.0	4,132.5	$0.0921436	$ 380.78
..	..	....	.....	.....	.....	.....
1	14	72.5	57.0	4,132.5	.....	380.78
..	..	....	.....	.....	.....	.....
1	15	12.5	213.65	2,670.62	.....	246.08
..	..	....	.....	.....	.....	.....
1	18	11.2	147.5	1,652.0	.....	152.22
..	..	....	.....	.....	.....	.....
1	19	72.5	59.0	4,277.5	.....	394.14
..	..	....	.....	.....	.....	.....
3	20	72.5	68.0	4,930.0	.....	454.27
..	..	....	.....	.....	.....	.....
6	21	72.5	60.0	4,350.0	.....	400.83
..	..	....	.....	.....	.....	.....
1	22	43.5	142.0	6,177.0	.....	569.17
..	..	....	.....	.....	.....	.....
Totals....	..	....	.....	161,366.65	.....	$14,866.14

ASSESSMENT FOR NORTHWESTERN AVENUE

Lot	Block	Rate	Length	Unit of benefit (3) × (4)	Unit assessment	Assessment (5) × (6)
1	2	3	4	5	6	7
3	15	1.2	86.6	103.92	$0.0870784	$ 9.05
..	..	....	.....	.....	.....	.....
12	15	10.6	213.65	2,264.69	.....	197.21
..	..	....	.....	.....	.....	.....
4	18	19.2	147.5	2,832.00	.....	246.61
..	..	....	.....	.....	.....	.....
7	22	28.6	142.0	4,061.20	.....	353.64
..	..	....	.....	.....	.....	.....
Totals....	..	....	.....	86,118.29	.....	$7,760.28

what different procedure must be followed in spreading the assessment for the work on the diagonal street, Northwestern Avenue. The most exact method would be to divide each lot into strips 1 ft. wide parallel to the street, but this involves an endless amount of labor in that particular instance. Another method which is sufficiently accurate for most projects is to draw a new benefit curve, on the same basis as the old, but for a width of zone determined by a perpendicular to the lot boundary lines in the zone. Such a curve is shown in Fig. 2, Curve *B*. The assessment may now be spread as before. The triangular-shaped lots may be assumed to have a depth equal to the average width or, if very precise results are desired, may be divided into strips 1 ft. wide parallel to the regular lots in the zone. The method of assessment for Northwestern Avenue is also shown in Table II.

Assessing Irregular Shaped Parcels.[1]—The method employed in the foregoing examples is accurate for rectangular shaped parcels of land, and nearly so for parcels that are nearly rectangular, but will introduce rather sizable inequalities if the parcels are triangular, or are sectors. When the zone to be assessed contains a few irregular shaped parcels, each may be divided into thin slices parallel to the pavement and the assessment determined by summing up the assessments of the slices, which are assumed to be rectangular. If there are many irregular parcels in a project, time will be saved in working out the assessment by using a mathematical method of determining the intensity of benefit for each irregular parcel of land. The method is also exact for rectangular shaped parcels but the benefits to these can more quickly be determined from curves or tables.

The first step in the mathematical process is to adopt an equation that represents the desired rate of diminishing benefits. A few trials will suffice to develop an equation that approximates closely any arbitrarily assumed rate. For example, Curve *A*, Fig. 2, is represented very closely by the equation

$$r = \frac{600y - y^2}{900} \tag{1}$$

where r is the intensity of the benefit at any distance from the improvement, and y is the distance from the property line of the

[1] Contributed by Ralph A. Moyer, Ass't. Prof. of Civil Engineering, Iowa State College, Ames, Iowa.

improved street to the point at which the intensity of the benefit is being determined.

In order to illustrate the application of Equation (1) to computations of assessments, two cases are considered.

Case I.—Base of a triangular parcel or the arc of a sector, lie toward the street for which the assessment is being made, as illustrated in Fig. 4.

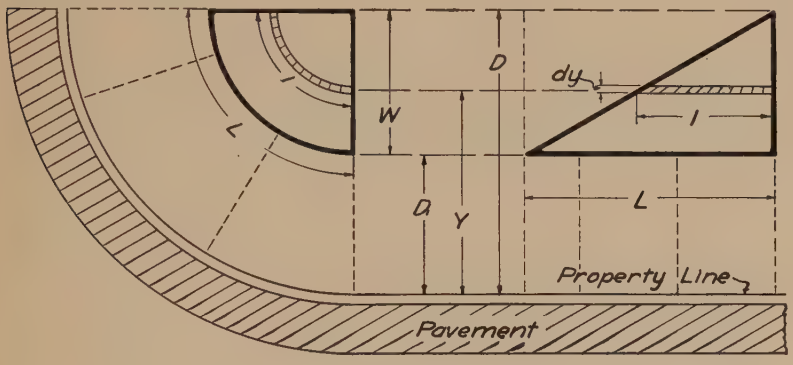

Fig. 4.

Solution for Case I.

$$\text{Let } r = \frac{600y - y^2}{900} \text{ (from Equation (1)).}$$

Where r is in units of benefit, and y in feet. The benefit on the elementary area ldy is ldr. The total benefit for the entire parcel is Σldr.

Then

$$dr = \frac{l}{450}(300dy - ydy) \tag{2}$$

From the geometry of Fig. 4 it is readily seen that

$$l = \frac{L}{W}(D - Y) \tag{3}$$

and by assembling the factors as defined above
Total benefit for either parcel in Fig. 4

$$= \Sigma ldr = \frac{L}{450W}\int_{D_1}^{D} 300Ddy - (300 + D)ydy + y^2dy$$

$$= \frac{L}{2700}\left[900W - 3WD_1 - W^2\right] \tag{4}$$

Case II.—Apex of a parcel toward the street for which the assessment is being made, as shown in Fig. 5.

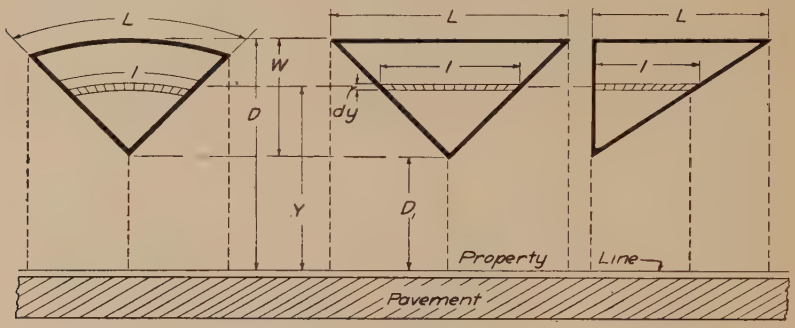

Fig. 5.

Solution for Case II.—By a method analgous to that employed for Case I, it is found that

Total benefit for either parcel in Fig. 5

$$= \Sigma ldr = \frac{L}{450W}\int_{D_1}^{D}(300dy - ydy)(y - D_1)$$

$$= \frac{L}{2700}(900W - 3WD_1 - 2W^2). \qquad (5)$$

Since the quantities W, D_1, and L are known for each parcel, the units of benefit can be calculated by substitution in either Equation (4) or Equation (5), according to the position of the parcel.

SELECTION OF PAVEMENTS

The type of pavement for a street is selected in many ways, as will be noted in the following outline. Generally the city authorities have the final word in the matter, although this is not always true.

Methods of Ordering Pavements.[1]—In 50 per cent of the cities heard from, any city street may be ordered paved by the common council, by a majority vote varying from one-half to five-sixths, it usually being two-thirds. In 30 per cent of the cities no new paving can be ordered except by a petition of from one-half to two-thirds of the abutting property owners. In 10 per cent of the cities the common council is permitted by ordinance to order a stipulated amount of new pavement each year.

[1] Report of Committee of Chamber of Commerce of Syracuse, N. Y.

How Type of Pavement Is Selected.—In only 15 per cent of the cities do the abutting property owners have the final decision in selection of type of pavement. In a few cases the common council, or even a single alderman, has the deciding power. In about 80 per cent of the cities, however, the type of pavement is selected by a paving commission, highway or engineering department, after due consideration of the wishes of the abutting property owners.

HIGHWAY ENGINEERING

It will be apparent from the foregoing that in the construction of roads and pavements many problems peculiar to the field of engineering will arise. Preliminary investigations, the selection of type of construction, the design of roads and pavements, the preparation of specifications, and the supervision of construction and maintenance all require a knowledge of principles that have been evolved by experience and experiment. The field of the highway engineer is thus apparent, and with the rapid expansion of systems of surfaced roads, and the greater attention that is being given to systematic maintenance, both for street pavements and rural highways, the need for trained men is obvious.

Problems

1. Make up an assessment schedule for each numbered tract in the area shown in the Waterloo district map, on the following basis: 20 per cent of the cost of the pavement is to be assessed against the land lying in a zone 3 mi. wide, half on each side of the improved road. The assessment district on each side of the road is to be divided into three zones. The rates for the several zones are to be 50, 35, and 15, respectively. The pavement cost is $28,000 per mile.
2. A system of roads was constructed entirely with funds obtained from the sale of 4.5 per cent serial bonds. The bonds in each issue were divided substantially equally into ten series, the first maturing in 11 years and the last in 20 years. The contract price for the construction averaged $30,000 per mile. What was the total tax levy required to pay for 1 mile of road? Would there have been a financial saving if the road system had been constructed as tax money became available, instead of by anticipating the taxes by means of bonds? If so, how much would have been saved? Have the tax payers profited in any way from the plan that was followed?
3. Prepare an outline embodying your idea of an equitable method of financing the repaving of a business street in a small city.
4. Complete the assessment roll for Hodge Avenue in accordance with the basis used in Table II.

CHAPTER II

SURVEYS AND PLANS FOR ROADS AND PAVEMENTS

By Lowell O. Stewart[1]

I. ROAD SURVEYS

The completeness and detail with which a road survey should be made depends upon the character of the improvement contemplated and whether the work is to be done by contract or by force account. Surveys by various engineers differ in many respects even though made for the same class of construction, and it is not possible to standardize them because of that fact. So far as the actual work of making the surveys is concerned, no principles are involved that are not involved in making surveys for other engineering projects. As with other surveys, the information obtained and the method of tabulation are adapted to the needs of the work in hand.

For the purposes of discussion it is convenient to divide all surveys into four general classes: reconnaissance surveys; surveys for earth roads to be graded by force account; surveys for hard-surfaced rural highways; and surveys for paving. These represent four broad classes of surveys which inevitably overlap to some extent.

Reconnaissance Surveys.—These surveys are of two kinds, the first of which is identical in purpose with the reconnaissance survey made in railroad work. Its purpose is to find the best location or route for a new highway, or relocation of an old one. This type of survey needs no explanation.

The second type of reconnaissance survey is one that has been adapted primarily to highway work and has for its purpose the selection, from among several roads, of the most feasible for improvement. It involves the examination of the road to secure data for the preparation of a map showing the various physical characteristics such as bridges, culverts, embankments, cuts, hills, the apparent width of right-of-way, the character of the

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soil, and any other fact that would have a bearing on the selection of a route.

Apparently such a survey differs widely from the ordinary reconnaissance and yet it serves substantially the same purpose, namely, the selection of a tentative route. The survey is made by walking or driving over the road. Distances are obtained by the pedometer or odometer and checked by intersecting roads and survey monuments when these are encountered. The notes are kept in the ordinary field book upon which the route has already been platted from existing maps so that it remains only to fill in the detailed information.

Surveys for Earth-road Construction.—For earth-road grading, especially blade-grader or elevating-grader work to be done by force account, it is not always necessary to make complete detailed surveys. Grading done by force account is not usually finished very closely to grade, nor will it be necessary to balance earthwork on the plans, because adjustments can be made in the field as the work progresses. The object of this kind of a survey is to give an approximate grade for the outfits to work to so that drainage will be assured and reasonable gradients result. The transit survey usually consists in running a center line and locating fence lines, bridges, culverts, and other physical characteristics relative to this line and to the adopted stationing. Houses, entrances to farms, trees, pole lines, bridges, and similar physical characteristics are indicated, as well as the type of soil encountered.

The level survey consists in running a center-line profile, and possibly a profile in each ditch. If a section is encountered where it appears that a considerable change in grade will be desirable, cross-sections are taken at 100-ft. stations and at intermediate breaks in grade, if such occur.

This kind of a survey is suitable for force-account grading and is permissible where funds are not to be had for a more complete detailed survey. It is used especially on earth-road grading or low-grade surfacing where the local conditions are such that the requirements are not exacting.

Complete Detailed Surveys.—Complete detailed surveys are a prerequisite to the preparation of plans for contract highway work except that which is performed on the cost-plus basis. These surveys are made in the following successive steps, which have become recognized as the usual practice in highway work:

1. The preliminary survey, which includes: special topographic surveys of relocations; the center-line survey; topographic surveys for bridges and grade separations at intersecting highways and railroads.
2. The right-of-way survey.
3. The construction survey.
4. The final-estimate survey.

THE PRELIMINARY SURVEY

The modern methods of highway transportation have necessitated the relocation of portions of many of the older roads before they are modernized. In a few instances, a new location may be selected on the basis of a study of an existing topographic survey of the area to be traversed, for which purpose maps of the United States Geological Survey are suitable. But since so small a portion of the United States has been mapped, a topographic survey will in most instances be necessary in planning relocations. As a general rule, either the plane-table or the transit-stadia method will be used for this survey, the scale adopted depending upon the size and configuration of the area to be mapped.

Where the final location is to be selected from a number of feasible locations, the engineer likes to make sure that all of the possibilities have been investigated. It is better to survey several lines that are later eliminated from consideration than to overlook one that later proves to be the most satisfactory.

All data obtained in these surveys should be clearly identified in the notebooks, and the surveyed lines should be shown on a sketch map of the entire project, drawn approximately to scale. The notes for each line should be indicated by means of a key number or letter, such as "line *A*," "line *B*," "line 27*C*," which should appear both on the map and in the notes.

THE CENTER-LINE SURVEY

The system of stationing and the datum for elevations should be established before the survey is begun. The stationing should be carried continuously from the beginning to the end.

Stationing.—When alternate lines are surveyed for a part of the route to provide data for possible relocations, the stationing on the alternate line will be referenced to the primary line by means of station equations. Assume that the primary line

is called *A* and an alternate line *B*, and the alternate line begins at Station 35 + 17.6 and ends at Station 65 + 38.8 of line *A*, and the alternate line is 2274.6 ft. in length. The appropriate station equations are:

$$B\text{-line Sta. } 0 + 00 = A\text{-line Sta. } 35 + 17.6.$$
$$B\text{-line Sta. } 22 + 74.62 = A\text{-line Sta. } 65 + 38.8.$$

The equality sign (=) is used to mean "coincides with."

The Survey.—The several operations which form the complete center-line survey may be listed as follows:

1. Staking the center line and taking the topography.
2. Establishing the bench marks.
3. Taking the cross-sections.

Staking the Center Line.—Each 100-ft. station on the center line is marked by a stake (called a "hub") set on line. If the survey line is on the traveled part of a road, these hubs may be large spikes thrust through a piece of red cloth and driven down until the head is about 3 in. below the road surface so as to escape the road maintainer. Where the line lies in fields and untraveled sections of road, a wooden stake is preferred. A marker stake, carrying the station number, should be driven near each hub, or at an indicated rectangular offset when the hub is on a traveled road.

In some instances, it may be known in advance that the construction line will follow exactly the preliminary line. Where that is true, it is well to place offset hubs with tacks on one or both sides of the road, at the time the preliminary line is run. These would be placed at an offset of 25 or 30 ft., opposite each 100-ft. station. Alongside each offset hub there is driven a marker stake upon which the station number is marked.

Unless other considerations make it impracticable, it will be desirable to run the surveys from west to east or from north to south, so that the plans may be oriented to conform with standard practice, that is, with north at the left or top.

Referencing Transit Points.—Each point on the line at which the transit is set up should be referenced very carefully. Many engineers prefer the method in which four reference points are selected in such a manner that the transit point is at the intersection of the X formed by connecting diagonally opposite reference points. These reference points may be permanent objects such as trees, boulders, wall corners, and the like, with

hubs set near by, or the hubs may be used alone, if no permanent object is convenient. Both types of reference point are desirable, the former for their permanence, the latter for the ease with which a transit may be set up over them and pointed to the elusive transit point.

The notes should include a sketch of the layout at each transit point showing the distances and direction from the transit point to the reference points and the kind of reference points.

Each transit point must be readily visible from the preceding and following transit points, but a half mile is about the maximum satisfactory distance between transit points, even though the instrument man may be able to see farther from some of the points.

Intersection Angles.—The intersection angle at each point of intersection (P.I.) of diverging sections of the line is measured and recorded. It may be measured by deflection or by measuring clockwise from the backsight, but one method or the other should be followed throughout the survey. Doubling the angle will guard against errors. Compass bearings are a valuable aid in detecting mistakes of a half degree or larger.

Horizontal Curves.—At points of intersection where the angle of intersection is larger than two degrees, a horizontal curve should be staked out with the stationing carried continuously around the curve. The type of curve and the degree will be fixed by the conditions and the standard practice of the organization for which the survey is being made.

Topographic Features.—As the party proceeds along the center line it should locate all objects that are likely to be of importance in connection with the design of the proposed improvement. This will generally include everything within a strip 150 ft. wide on each side of the center line, and certain additional data regarding drainage areas and the like. With a little practice, a man can pace the distances on the center line (between 100-ft. hubs), while distances to the right or left of the center line will be taped by others of the party who will also measure buildings and other structures. The following list gives the most of the objects that will be recorded in the ordinary highway survey:

1. Corner stones.
2. Section and quarter-section lines.
3. Division fences.
4. Side roads and the angle at which they intersect the main road.
5. Buildings.

6. Rows of trees, with notes as to kind, usefulness, and size.
7. Existing tile lines, with notes as to conditions, size, and outlet.
8. Field entrances and driveway entrances.
9. Sidewalks.
10. Culverts and bridges, with station of each end of large bridges.
11. Telephone lines and transmission lines.
12. Guard fence.
13. Retaining walls.
14. Gravel pits and quarries.
15. Limits of each property ownership and name of owner.

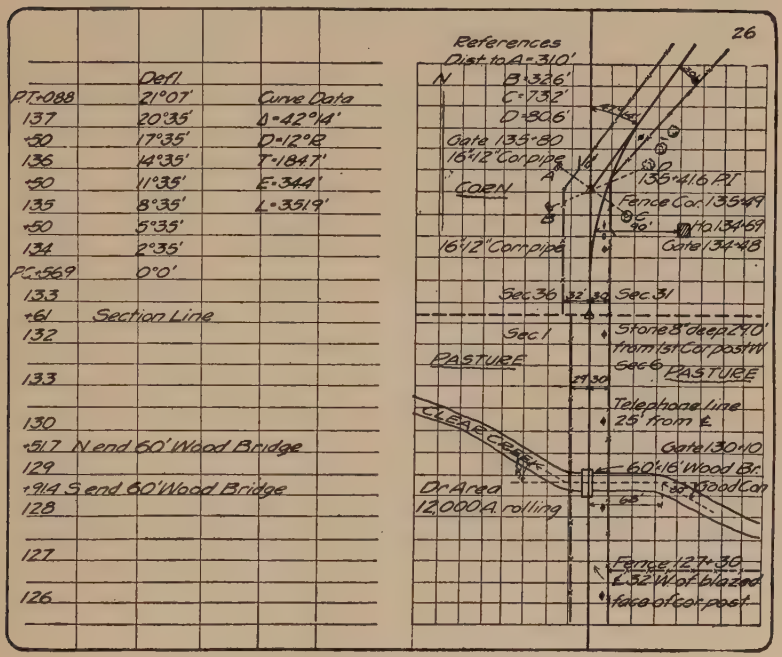


Fig. 6.—Typical transit survey field notes.

Notes.—A standard form of notes is shown in Fig. 6. The sketch is placed on the right-hand page and station numbers with notations are on the left. Both the sketch and notes begin at the bottom of the page, an arrangement which enables the notekeeper to record his data and draw his sketches with a minimum amount of mental juggling. The notes and sketches should never be crowded.

Corner Stones.—Survey monuments have been established for many purposes by various governmental and local agencies. Probably the earliest were those of the government land surveyors who measured and marked the land upon the ground. In the eastern states, these surveys were made by metes and bounds.

In the states farther west, the rectangular system of the General Land Office was used. As the land was settled and sold, resurveys and new surveys were requested and carried out. These surveys disclosed some errors in the original work. This impelled the General Land Office to establish the general rule that all corners must stand as actually set by the original surveyor, even though the position does not agree with the notes. The work of later surveyors has been to retrace the lines and reestablish and remark the original corners as nearly as possible.

The records of these original surveys were kept in the office of a surveyor-general who had charge of one or more states. When the surveys of a state had been completed, those records were turned over to the state officials, who held them open to reference by anyone. Local governmental units, such as the counties, had need for many of these data, so copies of the descriptions were furnished to each county. In most states, the county records now afford the only up-to-date descriptions of monuments, because of the fact that all surveys subsequent to the original government surveys are recorded in the county recorder's office.

The engineer who is engaged in making highway surveys has frequent occasion to locate the original survey monuments along a highway. These have, in many cases, been exposed by the wear of traffic or by grading operations, and in other cases, are buried and must be uncovered. Normally these monuments should be found at half-mile or lesser intervals, but the exact location of intermediate monuments is not readily determined in all cases because the original lines were not run with transit accuracy.

If a preliminary examination fails to unearth the desired monument, a systematic search must be inaugurated. The county records should be examined to ascertain just where the monument should be found. Additional information may often be secured from local engineers or surveyors, road maintenance crews, or residents of the neighborhood.

Datum and Bench Marks.—Sea-level datum is used if it has been established near the line to be surveyed. When neither sea-level nor local datum is available, an assumed datum is selected which is high enough to insure that no negative elevations will develop on the survey. A series of bench marks is established on the basis of the adopted datum. Bench marks should be in places that are not likely to be disturbed before or

during construction operations. Objects already in place are suitable and convenient, as a rule. Bridge abutments and wing walls, head walls of concrete culverts, concrete steps, and large boulders are good. A railroad spike driven into the root of a tree is satisfactory. In open country, pieces of iron pipe about 4 ft. long may be driven near the fence line.

In general, bench marks should be placed at quarter-mile intervals, and closer in rough country. One should be placed near each bridge, culvert, or similar structure. Each bench mark should have a number, beginning with N-1 at the zero end of the line, and each should be described very carefully to facilitate locating it when it may later be needed.

All bench-mark elevations should be checked very carefully. On short projects it will be quite satisfactory to check bench-mark elevations when the cross-sections are taken. On lines 1 mile or more in length, a separate set of check levels is desirable to obviate bothersome corrections in the cross-section elevations. In either case, the elevations of bench marks should conform to standard practice, which is that the difference in successive determinations of the elevation of two bench marks should not exceed $0.05\sqrt{D}$, where D is the distance in miles between bench marks.

Cross-sections.—Elevations on lines transverse to the center line, called cross-sections, should be taken at each 100-ft. station and at intermediate places where there are pronounced changes in the topography, whether the change is on the center line or at the side. The cross-sections should be extended to the right-of-way lines and as much farther as conditions warrant. This outer limit at any particular station will depend upon the depth of cut or fill and the width required by the cross-section of the proposed improvement. The engineer should visualize each situation with its probable grade line to make sure that he has extended his cross-sections to the proper limits.

Additional cross-sections should be taken at the ends of bridges and wing walls and at culverts. If the culvert is permanent, the distance back-to-back and the elevations of head walls should be recorded, to give data for determining the allowable height of fill. Railroad and trolley crossings will require special cross-sections or special surveys.

Intersecting Roads and Driveways.—Center-line profiles and cross-sections should be taken on side roads and driveways so

that the designer may establish a suitable approach. In level country, a profile extended about 300 ft. will suffice. But where the side road must be graded to fit the main road, enough cross-sections should be taken to permit the balancing of cuts and fills on the side road. Usually the center-line profile is the only data needed for a driveway.

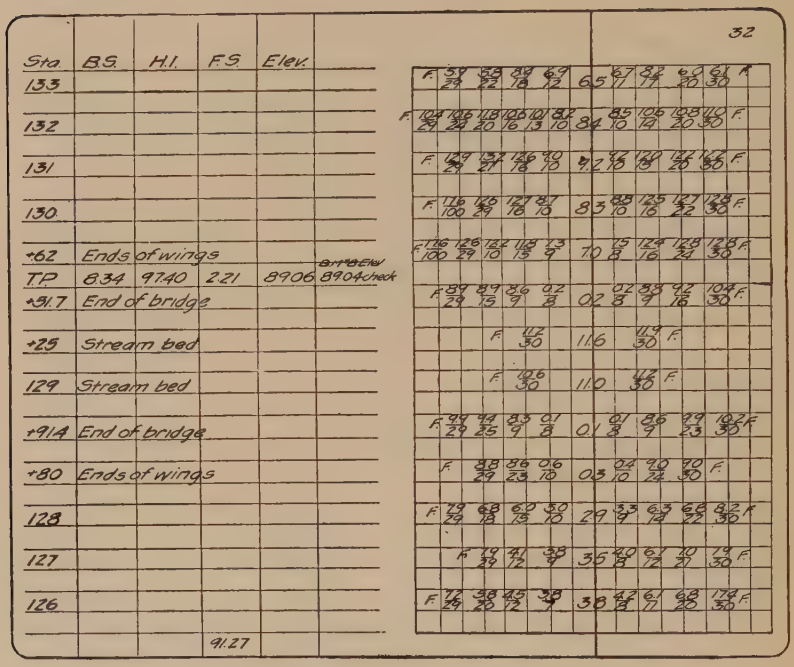


Fig. 7.—Typical level survey field notes.

Notes.—When recording the bench-mark levels, it will be convenient to have the notes read from the top of the page downward. But the cross-section levels are more easily recorded from the bottom of the page upward so that "right" and "left" in the book are oriented with "right" and "left" on the ground. Mistakes in the use of "right" and "left" are not infrequent and when surveys run in the cardinal directions, it is perhaps wise to use "east" and "west," or "north" and "south." "Right" and "left" have advantages on diagonal or winding roads. Cross-section notes must not be crowded. A good arrangement is shown in Fig. 7.

Topographic Surveys for Bridges and Grade Separations.—Frequently, a special topographic survey will be required at sites of proposed bridges to procure adequate data for the designer. This is a function of the preliminary party, although it is some-

times done by a party with special equipment. Either the transit-stadia or plane table-stadia method will be suitable. Usually a large scale, such as 40 ft. to the inch, with 1-ft. contours, will be desirable.

This topographic map should be supplemented by the following information with reference to an existing bridge: type, condition and date of construction; length of each span, number of spans; adjacent bridges up and down stream; high- and low-water elevations; stream velocity; evidence of silting or scouring; surface elevations; stream depths at several places up and down stream; whether stream carries debris; danger from ice; complete cross-sections for abutments and piers; and borings at abutment and pier sites to ascertain underlying soil conditions.

Grade Separations.—A similar topographic survey will be needed at crossings where grade separation structures are in existence or proposed. An extensive survey is frequently necessary to determine the most advantageous location for a new structure. Where an under- or overcrossing has already been built, a sketch-in plan and elevation may suffice. Additional information will generally be needed as follows: kind of structure; clear width of roadway and whether the structure is skewed or perpendicular to the road center line; the angle between road and railroad center lines. For highways passing under the tracks the following information should be secured: elevation of highway and top of rails; vertical clearance; number of tracks; drainage conditions; borings to indicate soil conditions.

RIGHT-OF-WAY SURVEYS

A right-of-way survey with the accompanying right-of-way plat and conveyance should be a requisite on all permanent highway improvements. In states that do not have the rectangular system of land surveying, the right-of-way survey will parallel the road center line, just as a tract of land would be traversed. In such surveys, accurate descriptions of points of beginning and ending and all intermediate traverse points are of fundamental importance.

In states having the rectangular surveys, the roads usually follow the section lines. Such cases are more or less standardized as to the form of the description. They may depart materially from the standard when the road is relocated. Points of beginning and ending should be chosen with care and judgment.

Usually they will coincide with a land survey monument (section corner).

The plat which accompanies the description is fully as important as the description. It should show the data of the field survey to a suitable scale. The plat of an extensive project may be conveniently shown on a roll of paper, using a scale of 400 ft. to the inch. Parcels requiring special detailed treatment may be drawn to an exaggerated scale opposite their proper places on the small plan. Such an arrangement facilitates field examination.

These right-of-way maps should show the following:

1. The center line of the highway.
2. Right-of-way lines and actual width of right-of-way.
3. Ties to pertinent land lines and monuments.
4. Official designation of the land sections through which the highway passes.
5. Streams.
6. Bridges and culverts.
7. Railroad and trolley right-of-way.
8. Telephone and power lines.
9. Any distinctive object that will serve to fix and establish the right-of-way for future reference.

CONSTRUCTION SURVEYS

The surveys that are likely to be required during construction may be listed as follows:

1. Checking plans and staking the center line.
2. Cross-sectioning and setting slope stakes.
3. Setting finish stakes.
4. Setting pavement stakes.
5. Staking bridges and culverts.
6. Referencing land monuments and transit points.

The first step in the construction survey should be to check the plans to ascertain any changes that were made from the preliminary line. This is a field operation. While it is being done, the construction stakes should be set. Where the line follows a traveled road, each 100-ft. station may be marked on line by a spike driven into the ground through a red rag. Each of these spikes should be referenced by hubs set at a uniform offset distance, say 30 ft., on one or both sides of the road. New P.I.'s and P.T.'s will be set and referenced, as was done during the preliminary survey.

Cross-sections.—The work of the cross-section party should be kept well ahead of the construction. A set of cross-sections will be taken at the time that the slope stakes are being set. These cross-sections are to be compared with the original cross-sections of the preliminary survey and should be taken at the same places. These should be at each 100-ft. station and wherever the ground makes a noteworthy change in slope between stations. Special care should be taken to secure the elevations at the points where there is neither cut nor fill (called "0.0 points"). Three of these elevations will be encountered in going from cut to fill or from fill to cut, one on each side in the ditch, and one on the center line.

Slope Stakes.—In general, slope stakes driven vertically should be set for each station at the toe of the slope in fills and at the top of the back-slope in cuts. Slope stakes for deep cuts are often disturbed by construction operations and it is desirable, at times, to offset the stake about 3 ft. to avoid its being loosened. The slope stakes will generally be set with an ordinary level, although a hand level will be found sufficiently accurate under some conditions. The depth of cut or fill at the sides of the section and at the center line, and the distance to the center line should be marked on the face of the stake and the station number should be marked on the back of the stake.

Finishing Stakes.—As the contractor finishes his rough grading, the engineer will set finishing stakes. These should be set at each station, or oftener, and be given special identification, such as a blue mark on the top which will represent the elevation to which the contractor will finish his grading. In fills, the stakes should be set to provide for settlement which will be about $\frac{1}{10}$ ft. for each foot of fill. This does not mean that the fill is widened. The fill is raised at the shoulder lines but the width is held. When the fill finally settles, the side slopes will be as prescribed by the plans, although they are actually steeper when the contractor finishes his work. Usually the roadbed will be finished to a level cross-section, and if so, the finishing stakes in both cut and fill will be set on the shoulder lines at the elevation of the center-line grade.

Pavement Stakes.—Additional lines of stakes will be required for the construction of a pavement. The engineer and the contractor should agree upon the details of placing these stakes in order that delays and misunderstandings may be reduced to a

minimum. Usually, a line of stakes will be required on each side of the proposed pavement, set at a convenient offset distance from the edge, at edge, or at center grade. A convenient spacing is 50 ft. on tangents and straight grades and 25 ft. on vertical and horizontal curves.

Staking Bridges and Culverts.—Bridges and culverts must line up with the road. To assure correct alignment the engineer should take his line from transit points and should not rely on intermediate hubs that are supposed to be on line. Several transit points should be set on line near the bridge site and be

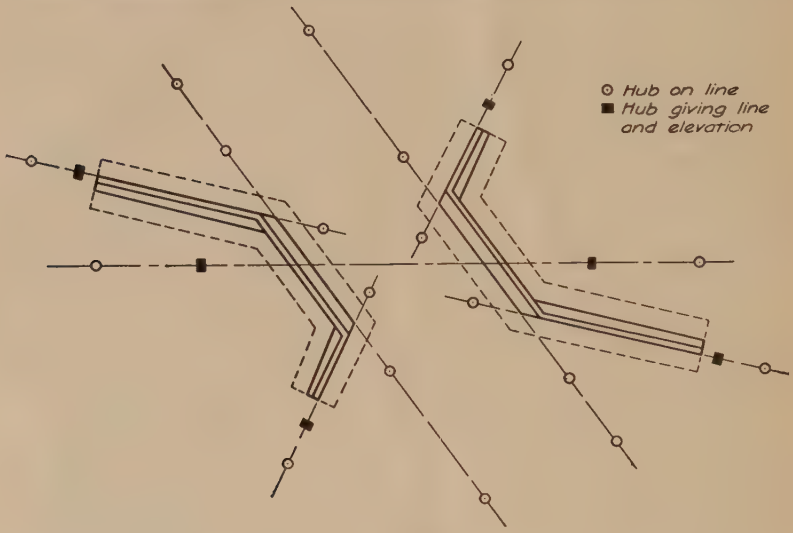


FIG. 8.—Illustrating a method of setting stakes for culvert construction.

carefully referenced for use during construction. Probably a piece of iron pipe, or iron bar, will be most satisfactory for that purpose. For small bridges and culverts one point on the center line on each side of the structure will suffice. These should be set outside the limits of construction operations. Greater care must be taken in providing reference points for large bridges that are likely to be under construction for some time. To make sure of a backsight at all times, two center-line points should be set on each side of the bridge, well beyond the limits of construction.

Bench marks for fixing the pier and abutment elevations are equally important. Permanence is the first requisite, but acces-

sibility should be considered when selecting the location of bench marks as they will be used many times with the instrument in various locations on the site.

Figure 8 illustrates a typical method of staking out a bridge. In setting the stakes the engineer should keep the needs of the contractor in mind. The latter is usually a practical and experienced man, but he must have enough stakes to fix the head walls, wing walls, and piers in the proper place and at the correct elevations.

Referencing Land Monuments and Transit Points.—During construction, everyone should be on the lookout for land monuments which may or may not have been found by the preliminary survey party. Each monument that is discovered should be carefully referenced so that it may be reset when the construction work is completed. In the case of an earth or gravel road the original stone or an iron bar may be reset in place and referenced permanently. With a pavement it will be necessary to drill a hole in the concrete above the stone or bar, and in it set a lead plug, a piece of pipe or an iron bar. The descriptions of monuments and references should be preserved most carefully and later recorded in the office of the proper official.

Transit points should be referenced and preserved in the same way, but they are not recorded. Usually all P.I.'s, P.O.T.'s, P.C.'s, and P.T.'s will be referenced. It is oftentimes desirable, for uniformity, to reference such points by four small concrete posts set so that lines connecting diagonally opposite posts will form an X with the transit point at the intersection of the two lines. These posts should be placed out of the way of mowers and graders, but in a conveniently accessible place. Probably a location near the fence line is most satisfactory.

FINAL ESTIMATE SURVEYS

All final payments on contracts should be based on a final survey. This would begin with taking cross-sections over the finished road at the same sections that were used for the first cross-sections. The difference between the two will give the *actual* cut or fill. Following this would come the measurement of all completed structures such as bridges, culverts, and the pavement itself. This can be done most satisfactorily by the resident engineer and the inspector.

As the engineer makes this final estimate survey, he should revise a set of construction plans to show the road as built. This can be done most readily by making proper notations on a clean set of blueprints. These notations should include changes in alignment and grade; station and description of each structure; land ties; bench marks; earthwork quantities; corrected locations of fences, buildings, landmarks, and the like.

II. ROAD PLANS

As might be expected, the plans prepared for road improvement vary in completeness and form among the various engineers and state departments. In general makeup they are much the same, consisting of a plan and a profile always, and frequently being accompanied by the cross-section for each station.

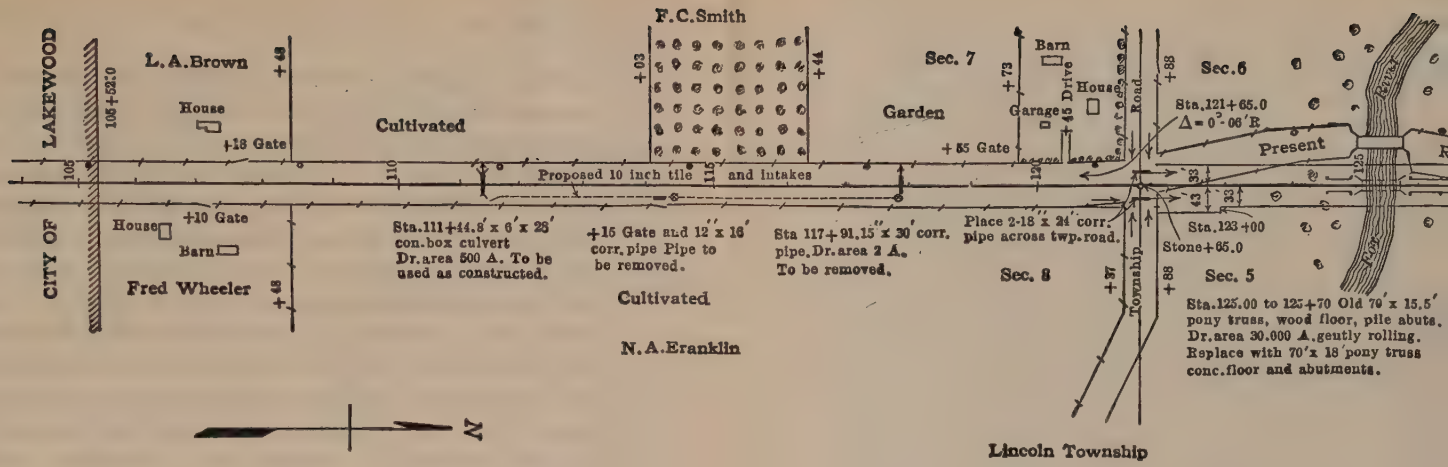
Profile.—A center-line profile is usually shown. It is sometimes the profile of the finished roadway, sometimes that of the foundation for the hard surfacing, and sometimes a "grade" profile or profile passing through the balance line of the cross-section. Probably the most common practice is to show the profile of the finished surface.

The scale to which the profile is drawn also varies greatly. A scale of 10 ft. per inch vertically and 100 ft. per inch horizontally, or of 200 ft. to the inch horizontally, is often used.

A horizontal scale of 40 ft. to the inch, and a vertical scale of either 8 ft. to the inch or 4 ft. to the inch, is also widely used and is probably the most satisfactory. Profiles drawn to this scale are voluminous and inconvenient to handle in the field, but are desirable from the standpoint of design.

The profile of the existing road surface and the established grade line are always shown and sometimes the profile of the ditches. The profile should also show all bridges and culverts, lines of tile, and catch-basins. The location of bench marks and their elevation is given, and the elevation of the established grade line is marked at every break in the grade line, and sometimes at every station. The name of the road, the date of the plan, and the scale are essential parts of the plan.

Plan View.—The plan view is usually on the same sheet as the profile and the horizontal scale is the same as the horizontal scale of the profile. The plan view is sometimes broken at turns or deflections and the center line maintained as a straight line so as to keep the plan on the sheet. On this view are shown the



Bench Marks

Sta.111+41. X on center west headwall 8 x 6 culvert.....Elev. 708.43
Sta.121+40. Top of 1" iron reference stake S.W. cor. road intersection. Elev. 724.20
Sta.134+00. Top of 4' boulder 36' right in fence.....Elev. 717.64

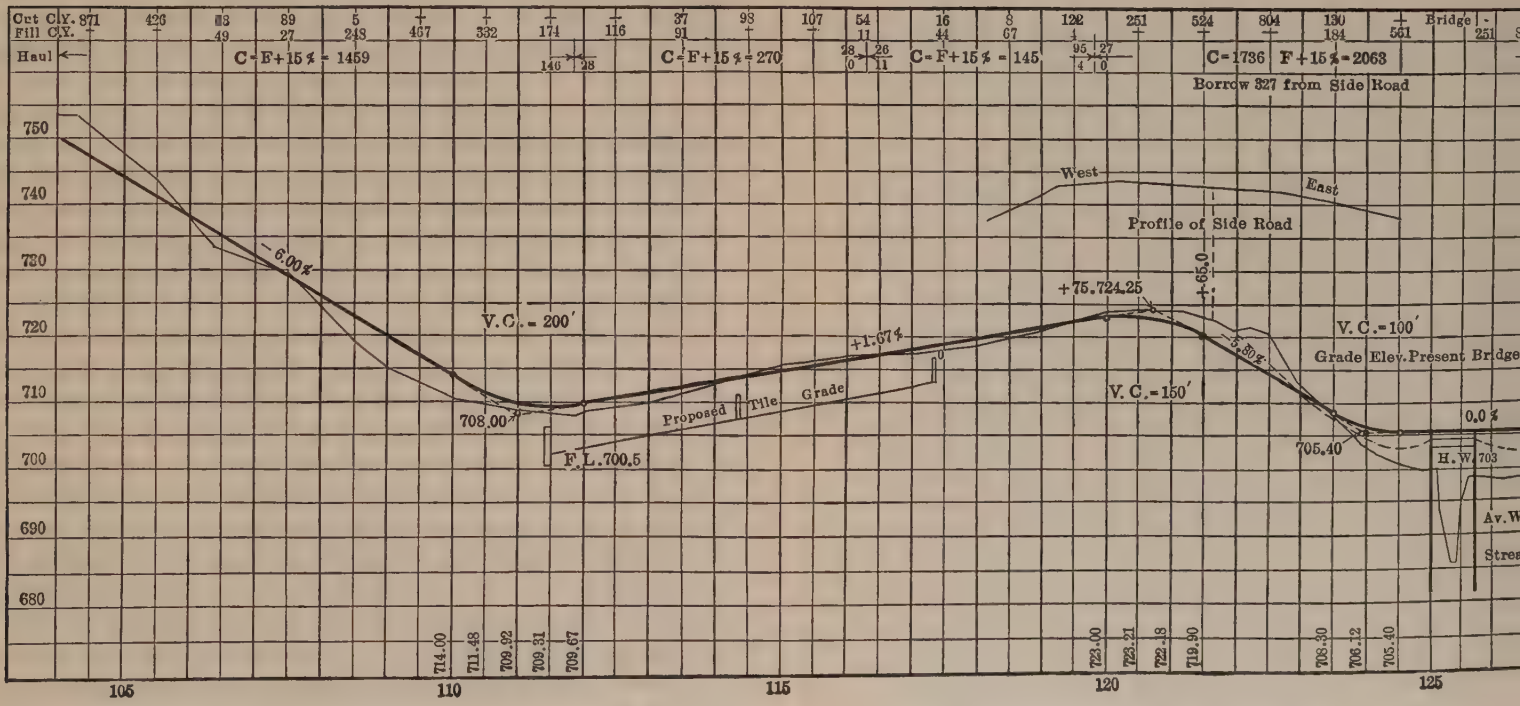
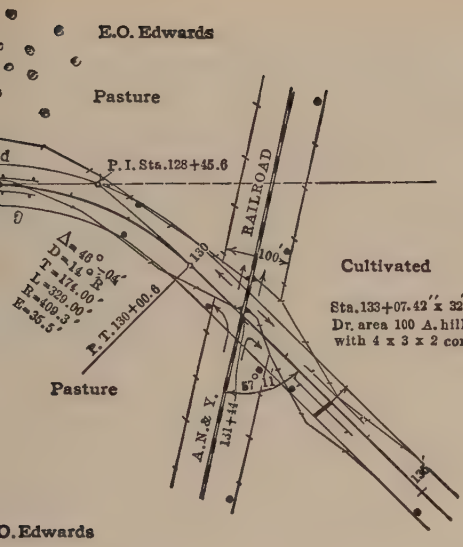
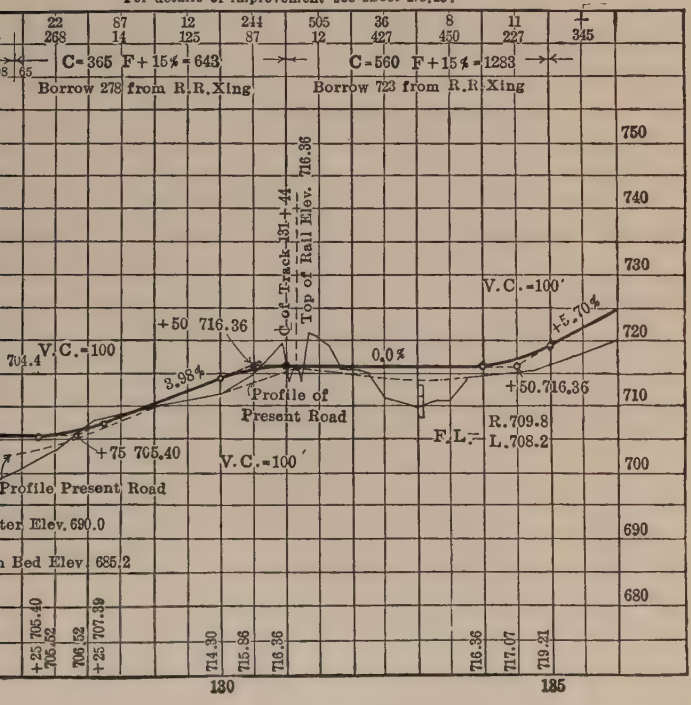


FIG. 9.—Plan for contract road construction.



Note:

Railroad crossing to be improved by beveling banks
For details of improvement see sheet No. 25.



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existing features such as fences, culverts, bridges, houses, driveways, intersecting roads, and such other information as may assist in the design. The lines of the hard surface and the location of any bridges or culverts to be built are also shown.

Cross-sections.—The cross-sections are platted in computing the quantities of earth work and are of use in construction in showing where surplus material is found and where it is to be deposited. Usually, the area of each cross-section and the quantity of material between sections is indicated. The sections are platted to a scale of 10 ft. per inch, 8 ft. per inch, or 4 ft. per inch. The larger the scale the more accurately the cross-section areas can be obtained, but the sections become exceedingly voluminous if platted to a scale of 4 ft. to the inch. Figure 9 shows a typical road plan.

SURVEYS FOR CITY PAVING

The surveys made as a preliminary to city paving must be made with greater accuracy and detail than is necessary for road surveys because of higher property values, more exacting requirements as to connections to existing and proposed improvements, and more rigid requirements as to drainage.

Monuments.—As with highway surveys, one of the first steps should be the making of a thorough search for monuments. Here the engineer will find many perplexing and conflicting conditions that require very good judgment and considerable ingenuity for their satisfactory and equitable solution. Oftentimes, monuments that once existed at street intersections and on property lines cannot be found. In such a case the engineer must seek to harmonize existing building and sidewalk lines with the requirements of the plat. Frequently, a property line that is satisfactory in one block will not fit an adjacent block, although the street line is supposedly on a straight line. Vexing excesses and deficiencies in street measurements arise in many small towns and cities. The engineer must proceed with all of these things in mind and remember that his final location must depend upon good common sense and sound engineering principles.

General Method.—In many instances, one survey will suffice for both the preliminary and the construction survey. Methods of construction and differences in opposite curb elevations necessitate curb lines and elevations so that the center line is not needed as the reference line. Each curb line should be projected through

as long a distance as possible with due regard to existing and future paving and symmetry about the street center line.

The hubs should be set at 25-ft. intervals on an offset line 2 or 3 ft. back of the face of the proposed curb. On steep grades the interval might be increased to 50 ft. In the business district, where most of the roadway space will be taken up by the pavement, it will be convenient to cut small crosses on the sidewalk in lieu of the hubs.

The data of the preliminary survey should consist of everything that relates to existing structures and conditions. This would include the location and elevations of building entrances, sidewalks, driveways and alleys, poles and electroliers, hydrants, manholes, culverts, inlets, railroad and car lines, underground pipes with notations as to their condition, outlets, and the drainage area of the street.

Cross-sections.—Cross-sections should be taken in the usual manner at 50-ft. intervals. Elevations should be taken on the top of hubs to the nearest hundredth of a foot with particular care for check elevations both before and during construction. Bench marks should be frequent and permanent. A standard type of concrete bench mark is best, but lacking that, fire hydrants will be satisfactory. During the leveling, particular attention should be given to the elevation of intersecting streets, both paved and unpaved, as well as all alleys, driveway openings and sidewalks, to make sure that the designer will have sufficient data to lay out his part of a harmonious whole.

Oftentimes, it is convenient for reference and the computation of costs to survey each block as a unit; beginning anew at zero after crossing an intersection.

Stakes.—The stakes of the preliminary survey will be supplemented as construction proceeds. Additional stakes should be set for alley returns, for all curves if not completely staked during the preliminary work, and for tangent points and centers of curb arcs at intersections. Where "built up" forms are used for these small curves, hubs for the two tangent points will fix the location and the hub for the center of circle will not be needed. A grade stake will be needed to fix the elevation of the mid-point of the curve. Enough stakes should be set in the intersection to guarantee a finished surface that will conform to the plans.

When one set of stakes is used in this manner it will be convenient to furnish the foreman with a sheet giving cuts and fills

at each station. Setting the tops of the hubs to grade or marking them an even number of feet above or below grade, requires considerable time and is frequently impracticable. A good form setter can do satisfactory work from the indicated cuts and fills. When his string for the top of curb is stretched, errors in alignment and elevation can be discerned by eye. After the forms are set the engineer should make a second inspection by eye. This should suffice except in the cases of grades under 0.3 per cent, where an instrument should be used to check the forms to avoid water pockets.

PLANS FOR PAVING

Plat.—Usually a complete set of plans for a street improvement will include a plat of the city, or a portion of the city, with the proposed paving district and streets to be paved indicated thereon. Curb radii, catch basins, curb inlets, storm sewer lines, valley gutters, crossing plates, and similar special features may be shown most conveniently on the larger scale plan, which is placed above the profile on the standard plan-profile.

Profiles.—The plan and profile may be shown most conveniently on standard plan-profile paper or cloth. The plan, which is usually placed above the profile, should show all features that may be useful to the designer. The most convenient scale is 100 ft. to the inch.

The profile of the center line of the proposed pavement is sometimes useful and may be plotted. In laying the grade the engineer should make his design conform to the established grade, if there is one. If there is no established grade, he should try to fit his pavement to existing structures, side-walks, ntersecting streets, and the general lay of adjacent property.

Frequently, the elevations of opposite points on the two curbs will be different and the elevations of both must be shown. The two curb grade lines may be drawn on the plan if the difference in elevation permits. It will be desirable to show the two curb line elevations and the property line elevations at each station, at each change in grade, and at alley and street intersections. This can be done conveniently by setting down the elevations in a systematic way. For example, the North (East) property line elevation would be placed at the top; slightly below it would be placed the North (East) curb grade elevation. The middle section would have the center-line profile and curb grade lines.

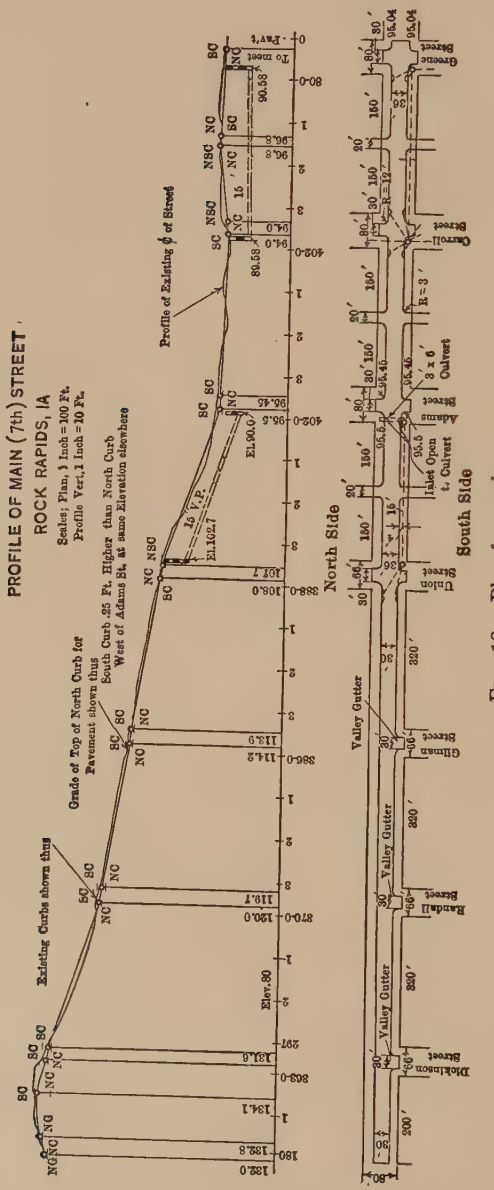


FIG. 10.—Plan for paving.

At the bottom would be the South (West) property line elevation; slightly above it the South (West) curb grade elevation.

The horizontal scale of the profile will be the same as that of the plan. The vertical scale will depend upon the flatness of the topography, but is generally 10 ft. to the inch, except where the topography is very flat.

If the gutter is not parallel to the top of the curb, as sometimes happens because of the requirements for drainage where flat grades are used, there should be a special note indicating the difference with its place of beginning and ending.

Cross-sections.—A sheet showing the details of the cross-section for the pavement will be included, but usually the cross-sections at each station are not included. These will be platted up for use in computing the quantity of earth-work but are not required for laying out the work. If several widths of pavement are included, a single typical cross-section may be shown, with a note indicating how the total crown will vary with the width of pavement.

General Information.—Generally several sheets of special details will be required in order to show the design of catch basins, curb inlets, manholes, crossing treatment at intersections, and similar minor details.

Problem

1. Have the Surveying Department assign as one problem the survey of a half mile of highway or a few blocks of a city street, the notes to be worked up and plotted in accordance with one of the standard methods of preparing road or street plans.

CHAPTER III

DRAINAGE AND CONTROL OF EROSION

I. DRAINAGE IN HUMID CLIMATES

General Problem.—In areas where the annual precipitation exceeds 25 or 30 in., two distinct drainage problems will be encountered in connection with road construction. The first involves the disposal of storm water and water resulting from melting snow and ice, in such a manner as to prevent the soil under the roadway from being made unstable through partial saturation with water. This requires a drainage system designed to effect the prompt removal of storm water from the proximity of the road. The second is the prevention of the percolation of underground water into the soil under the roadway. Such water originates in precipitation but may flow some distance through the soil before reaching the highway. The former is for convenience referred to as surface drainage, and the latter as under drainage.

Side Ditches.—The cross-section usually adopted for a public highway lends itself naturally to the construction of drainage channels at the side of the traveled portion of the road, and these are commonly referred to as side ditches. In many cases a simple design of side ditch is adequate but quite frequently conditions are encountered where special provision should be made for disposing of storm water.

Run-off.—The amount of water to be carried away is the run-off from the area contributing to the ditch. Primarily this water comes from the portion of the road between the ditches and the surface of this area is likely to be hard baked or covered by an impervious wearing surface. It may be assumed that for storms of a very short duration not more than 75 per cent of the water that falls on the road will run off to the ditches, but that for storms exceeding 15-min. duration, all the water will run to the ditch.

Some water will run to the road ditches from the area between the ditches and the right-of-way lines and from adjacent lands

that slope toward the road. The rate of run-off from this area will depend upon the slope, the character of the soil and the nature of the growth thereon. Cultivated lands will absorb practically all of the water from storms that last an hour or more except when the storms recur so frequently that a condition of saturation is maintained in the soil. Rocky soils will absorb very little water after the first few minutes. Flat lands will absorb more water than those that are sloping. All of these things may properly be taken into account in estimating the amount of water that will reach the side ditches. For general purposes it may be assumed that for storms of more than 40-min. duration all of the water falling on the drainage area will run to the side ditch. Knowing the total area, the rainfall characteristics of the region, and the slope that may be obtained, the area of cross-section of the ditch may be computed by determining the velocity by means of the familiar Chezy formula, using Kutter's formula for determining C. For the usual highway condition N in Kutter's formula may be assumed as 0.022.

While it is not necessary to go to this refinement in the design of side ditches for many conditions, there are many examples of failure of surface drainage due to the inadequate capacity of the side ditches. A careful analysis should be made where the side ditches must carry the water for long distances, or where a considerable area adjacent to the highway drains to the road ditches. In this latter case, especially in hilly country, a surprisingly large volume of water may reach the highway.

Shape of Ditch.—The side ditch may be V-shaped or may have a trapezoidal cross-section as may be preferred. Both types of ditch are used extensively and there does not seem to be any particular advantage to either. It is somewhat easier to construct the V-shaped ditch with the road grader, but the flat-bottom ditch is easier to construct with slip or wheel scrapers.

Supplementary Ditches.—It is often desirable to intercept, by means of a supplementary ditch roughly parallel to the road, water flowing from adjacent land toward the road ditch. The supplementary ditch is especially advantageous when the amount of drainage area to be provided against is large or the slope toward the road such as to make it difficult to control erosion. The slopes of cuts can be protected in this way by means of a supplementary ditch about 10 ft. back of the upper edge of the side slope.

Drainage of Embankments.—The removal of storm water from a road surface located on an embankment is given little consideration where the embankment is not high or long. But on long, high embankments the maintenance of the side slopes becomes a troublesome problem if storm water is allowed to flow over the edges at will. The alternative is to construct a ridge along the edge of the roadway to confine the water and then to carry it down the slope in paved gutters placed at intervals of about 150 ft.

Tile to Supplement Side Ditches.—If side ditches with flat grades must carry storm water for long distances, it is to be expected that the ditches will carry a large volume of water for a considerable period of time. Sufficient water may percolate under the roadway during this period to lower its stability. To expedite the removal of the ditch water, tile drains are laid below the side ditches to supplement the ditch. To be effective such tile must be of ample capacity and have a suitable outlet so that full advantage may be taken of the capacity. Frequent catch-basins or inlets should be provided to carry the water from the ditch to the tile. These may be of masonry, concrete or tile, but must be provided with a bee-hive grating on top so that they will not readily clog with weeds or other trash carried by the water. The so-called blind catch-basin, which is merely a section of about 3 ft. of the trench back-filled with broken stone, tile bats or gravel, will also serve the purpose.

The principal advantage of supplementary tile is realized when snow or detritus has blocked the ditches to some extent. When the snow begins to melt, often accompanied by rain, the ditch will not be fully serviceable, but the water will find its way to the tile through the frequent catch-basins. Generally the storm water will have passed through the tile before much ground water from the same storm reachs the tile, so that the tile will also serve to lower the ground-water level. In continued wet weather the efficiency of the tile in lowering ground-water will be reduced by using it to carry storm water.

Ground Water.—The storm water that goes into the soil flows slowly laterally and downward, its course depending upon a great many conditions of soil and topography. The distance from the surface of the ground to the ground-water varies greatly, being much less in the lower levels than in high ground. Underground water may be the cause of instability in the soil under a road and

very often is the cause of failures of roadway surfaces. The level of underground water may be held to such a depth that it will not jeopardize the stability of the soil supporting a road surface if properly designed tile drains are employed.

It will be convenient to consider three distinct conditions that are encountered in providing tile drains for highways. The first has already been mentioned in connection with surface drainage and is the case where the tile drain serves to supplement surface drainage in addition to lowering the ground-water level. For tile drains of this character the safe rule is to provide sufficient capacity for both purposes on the assumption that water is being delivered to the tile from both sources simultaneously.

The second is the case where the tile is employed to lower the ground-water level of roads with low rates of grades, that is, roads in generally level country. Here the generally accepted principles of land drainage may be employed except that it is desirable to place two lines of tile along the road at a depth sufficient to lower the ground-water level to at least 4 ft. below the road surface. On the basis usually adopted for land drainage one line of tile would be adequate to drain the right-of-way of a road 4 rods wide, but experience has shown that this is not generally true and that two lines of tile are needed. It seems to be established that the carrying capacity should be one and one-half times that considered sufficient for land drainage in order to expedite the removal of water. The minimum depth for the tile is 6 ft. below the elevation of the center line of the road.

The third condition is encountered in hilly country more frequently than elsewhere but is likely to exist under any topographical condition. It is manifested by seepages of water in the most unexpected places and by partial saturation of the road surface in locations remote from accumulations of surface water. These are evidences of underground water which, in following along on top of dense strata or in veins or porous layers in the soil, finally reaches the surface of the ground, or near enough to the surface to affect the stability. This condition results from the erratic behavior of underground water in hilly country and sometimes even in prairie country. Where the layers of each type of soil are nearly horizontal and of considerable thickness, it is comparatively easy to predict the behavior of underground water. When the soil consists of thin layers or pockets of materials of greatly different porosity lying at various angles with

the horizontal, and more or less faulted, it is impossible to predict the trend of underground water. This condition exists not only where ledge rock, shale, or dense clay underlies the surface soil, but also where the more porous clays, gravelly soils, or sandy loam underlie the surface.

The drainage requirements for roads where such conditions exist will be exceedingly variable and can only be determined by careful surveys of the road prior to beginning construction work and during the progress of the construction. In regions where the soil freezes to a depth of several feet, the most reliable information will be obtained by an examination of the road just after the frost comes out of the ground in the spring, and during the month or six weeks subsequent thereto. In regions where the ground does not freeze the examination is most advantageously made during the season of maximum precipitation and immediately subsequent thereto. The purpose of the examination is to locate those sections of road that are affected by underground water. When these are found, the exact nature of the flow of underground water can be determined by test holes, and the drains designed in accordance with the exact conditions encountered.

The topographical conditions that are most likely to require examination are side-hill cuts, moderately deep cuts, hills and sections of road that lie somewhat lower than the land alongside. Hills or elevations some distance away may be the source of water that finds its way to the supporting soil of a road.

The drainage method for all of these conditions is to lay tile so as to intercept the flow of water at a depth of 5 or 6 ft. below the surface of the road and the exact design will vary with conditions. It is a wise precaution always to lay tile drains along the foot of the slope in cuts and to back-fill the trench with broken stone or coarse gravel to facilitate the entrance of water into the tile. The size of tile to use is purely a matter of judgment as there is no means for computing it.

Subgrade Drainage.—The purpose of subgrade drainage is to minimize the effect of water upon the load supporting capacity of the material upon which the roadway surface rests.

It is important to have a clear conception of the difference between water that is flowing through the soil, and water that is held in the soil by capillarity. The former is moving more or less slowly, and its quantity at any one time will depend upon the

external supply available to replenish that which has begun its journey through the soil, the porosity of the soil and the artificial means taken to hasten flow through the soil. The actual quantity of such water will therefore vary from the amount that will produce complete saturation to a quantity so small as to be negligible. It follows that in regions of low precipitation there will never be a considerable amount of such water in the soil. The latter is held in the soil by capillarity and the quantity at any one time will depend upon the texture of the soil, the amount of water retained by the soil at a level that will permit it to rise through capillary action, and the opportunity for the water to be eliminated through evaporation after it rises to the surface.

Properly designed drainage systems will hasten the passage of storm water through the soil and may reduce the supply available to capillary action.

No satisfactory means have, as yet, been devised for controlling capillary water and in humid regions the soil under a road crust is usually moist even in hot, dry, weather. Since the subgrade is covered by the road crust, there is little evaporation and the quantity of capillary moisture in the subgrade soil will change but slowly during continued dry weather. On the other hand subgrade moisture will increase in quantity during prolonged periods of precipitation due to the ground water that is flowing through the soil.

There is considerable evidence to indicate that even with the most elaborate drainage provisions, there will be periods when the subgrade under the road surface will contain so much water that it will have very low supporting power. The investigations of Clifford Older[1] indicate that the road surface must be designed to distribute the live load over a very large area of the subgrade without deflecting sufficiently to rupture. Older has shown that enough storm water reaches the subgrade through cracks in the roadway surface and between the edge of the slab and the shoulder, to saturate the subgrade.

There is enough capillary water held in the soil even in dry weather to preclude the possibility of ever achieving a dry subgrade except with very porous soils. Many soils retain the water with great tenacity.

Two methods have been proposed for minimizing the effects of capillary water on the subgrade. Prof. F. H. Eno, of Ohio

[1] Older, Clifford, "Highway Research in Illinois," in *Proc. A. S. C. E.*, February, 1924, p. 193.

State University, has suggested placing a layer of about 6 in. of gravel, broken stone, or other porous material under the pavement slab to permit the circulation of air and the removal of some of the water by evaporation. The other method requires the admixture of portland cement or some similar material with the subgrade soil to stabilize it. These suggestions may result in the development of adequate methods of stabilizing the subgrade, but in the present state of knowledge of the subject it seems wise to predicate the design of the road slab on the theory that the subgrade will at times be of very low bearing value, if the road is located in the humid regions and on clay or loam soil.

With surfaces such as gravel, macadam, or asphaltic concrete, the road crust can adjust itself to subgrade movements and rupture will not occur unless the subgrade movement is considerable, although the surfaces will gradually become uneven. Drainage construction designed to minimize the amount of ground water will undoubtedly assist in maintaining the stability of surfaces of this type.

II. DRAINAGE IN ARID AND SEMI-ARID REGIONS

General Problem.—In arid and semi-arid regions the problem of drainage is primarily one of controlling surface water. It is exceeding rare to find a need for under-drainage in such climates, except that springs or seepy places may occasionally exist in mountainous districts.

Run-off.—In semi-arid and arid regions the little rain that falls may come during a very short rainy season and while the total annual precipitation may be less than 15 in., the rate of precipitation may be high. Usually the run-off from such areas is relatively high and flood conditions may prevail for short periods of time. The ditches required to accommodate properly the flood flow may be of as great capacity as those usually constructed in humid regions, but they may be dry for many months in the year. The run-off should be estimated on a basis of the recorded maximum rate of precipitation and the ditches designed on that basis.

Erosion.—An important part of the problem of drainage in semi-arid regions has to do with the control of erosion, which subject will be discussed in another place.

III. CULVERTS

Purpose of Culverts.—The culvert is an important part of the drainage for a highway system, being employed to carry the water from small streams across the highway or to carry the ditch water from one side of the road to an outlet on the opposite side. No uniformity exists in the various states in regard to the distinction between "culvert" and "bridge." This discussion is limited to structures of 6-ft. span or less.

Culverts should so far as possible be constructed at such a height that they will not make it necessary to raise the profile of the road in order to carry the roadway over the culvert. In some instances in very flat sections of road this is not possible and it becomes necessary to raise the road grade at the culvert. At such places the slope should be carried a sufficient distance each side of the culvert to insure an easy-riding crossing. Abrupt raises at culverts are uncomfortable for traffic and often are dangerous.

The culvert should be fitted to the traveled way so as to be practically unnoticeable until the traveler is close to it. It should also fit the stream so that the water will flow through with the least disturbance of its natural course consistent with reasonable economy.

The bottom of the culvert should not be placed too low, because of the tendency for the stream above the culvert to erode to the level of the culvert floor. If the stream has eroded a deep channel, the culvert proper may be placed at the level of the existing stream bed so that the lower end will discharge without causing undue erosion, but the upper end may be provided with a drop inlet, the top of which is several feet above the old stream bed. The stream bed above the culvert will gradually fill up to the top of the drop inlet, and thus valuable land will be reclaimed.

The size of culvert is best determined by estimating the drainage area contributory to it, and then applying one of the well-known formulas to determine the area of waterway. One of these formulas is shown in Table III.

Table III.[1]—Talbot's Formula for Waterways

Area of Waterway in Square Feet $= C\sqrt[4]{(\text{Drainage Area in Acres})^3}$

C being variable according to circumstances thus:

"For steep and rocky ground C varies from ⅔ to 1. For rolling agricultural country subject to floods at times of melting snow, and with length of valley three or four times its width, C is about ½, and if stream is longer in proportion to the area, decrease C. In districts not affected by accumulated snow, and where the length of valley is several times its width, ⅓ or ⅙ or even less may be used. C should be increased for steep side slopes, especially if the upper part of the valley has a much greater fall than the channel of the culvert."

The following tables gives ¼ roots of cubes, or the value of area of waterway for $C = 1$.

Acres	Sq. mi.	$\sqrt[4]{A^3}$	Acres	Sq. mi.	$\sqrt[4]{A^3}$	Acres	Sq. mi.	$\sqrt[4]{A^3}$	Acres	Sq. mi.	$\sqrt[4]{A^3}$
1	0.002	1.0	56	0.09	20	525	0.82	110	5,500	9	639
2	0.003	1.7	58	0.09	21	550	0.86	114	6,000	9	682
3	0.005	2.3	60	0.09	22	575	0.90	117	6,500	10	724
4	0.006	2.8	65	0.10	23	600	0.94	121	7,000	11	765
5	0.008	3.3	70	0.11	24	625	0.98	125	7,500	12	806
6	0.009	3.8	75	0.12	26	650	1.02	129	8,000	13	846
7	0.011	4.3	80	0.13	27	675	1.05	132	8,500	13	885
8	0.013	4.8	85	0.13	28	700	1.09	136	9,000	14	924
9	0.014	5.2	90	0.14	29	750	1.17	143	9,500	15	962
10	0.016	5.6	95	0.15	30	800	1.25	150	10,000	16	1,000
11	0.017	6.0	100	0.16	32	850	1.33	157	10,500	16	1,037
12	0.019	6.4	105	0.16	33	900	1.41	164	11,000	17	1,074
13	0.020	6.8	110	0.17	34	950	1.48	171	12,000	19	1,147
14	0.022	7.2	120	0.19	36	1,000	1.56	178	13,000	20	1,217
15	0.023	7.6	130	0.20	38	1,050	1.64	184	14,000	22	1,287
16	0.025	8.0	140	0.22	41	1,100	1.72	191	15,000	23	1,355
17	0.027	8.4	150	0.23	43	1,150	1.80	197	16,000	25	1,422
18	0.028	8.7	160	0.25	45	1,200	1.88	204	17,000	27	1,489
19	0.030	9.1	170	0.27	47	1,250	1.95	210	18,000	28	1,554
20	0.031	9.5	180	0.28	49	1,300	2.03	216	19,000	30	1,618
21	0.033	9.8	190	0.29	51	1,350	2.1	223	20,000	31	1,682
22	0.034	10.2	200	0.31	53	1,400	2.2	229	22,000	34	1,806
23	0.036	10.5	210	0.33	55	1,500	2.3	241	24,000	38	1,928
24	0.037	10.8	220	0.34	57	1,600	2.5	253	26,000	41	2,048
25	0.039	11.2	230	0.36	59	1,700	2.7	265	28,000	44	2,165
26	0.041	11.5	240	0.38	61	1,800	2.8	276	30,000	47	2,280
27	0.042	11.8	250	0.39	63	1,900	3.0	288	35,000	55	2,559
28	0.044	12.2	260	0.41	65	2,000	3.1	299	40,000	62	2,828
29	0.045	12.5	270	0.42	67	2,100	3.3	310	45,000	70	3,090
30	0.047	12.8	280	0.44	68	2,200	3.4	321	50,000	78	3,344
32	0.05	13.5	290	0.45	70	2,300	3.6	332	55,000	86	3,591
34	0.05	14.1	300	0.47	72	2,400	3.8	343	60,000	94	3,834
36	0.06	14.7	320	0.50	76	2,600	4.1	364	65,000	102	4,071
38	0.06	15.3	340	0.53	79	2,800	4.4	385	70,000	109	4,304
40	0.06	15.9	360	0.56	83	3,000	4.7	405	80,000	125	4,757
42	0.07	16.5	380	0.59	86	3,200	5.0	425	90,000	141	5,196
44	0.07	17.1	400	0.63	89	3,400	5.3	445	100,000	156	5,623
46	0.07	17.7	420	0.66	93	3,600	5.6	465	120,000	188	6,447
48	0.08	18.2	440	0.69	96	3,800	5.9	484	140,000	219	7,238
50	0.08	18.8	460	0.72	99	4,000	6.2	503	160,000	250	8,000
52	0.08	19.4	480	0.75	103	4,500	7.0	549	180,000	281	8,739
54	0.08	19.9	500	0.78	106	5,000	7.8	595	200,000	312	9,457

[1] Office and field practice of Iowa Highway Commission.

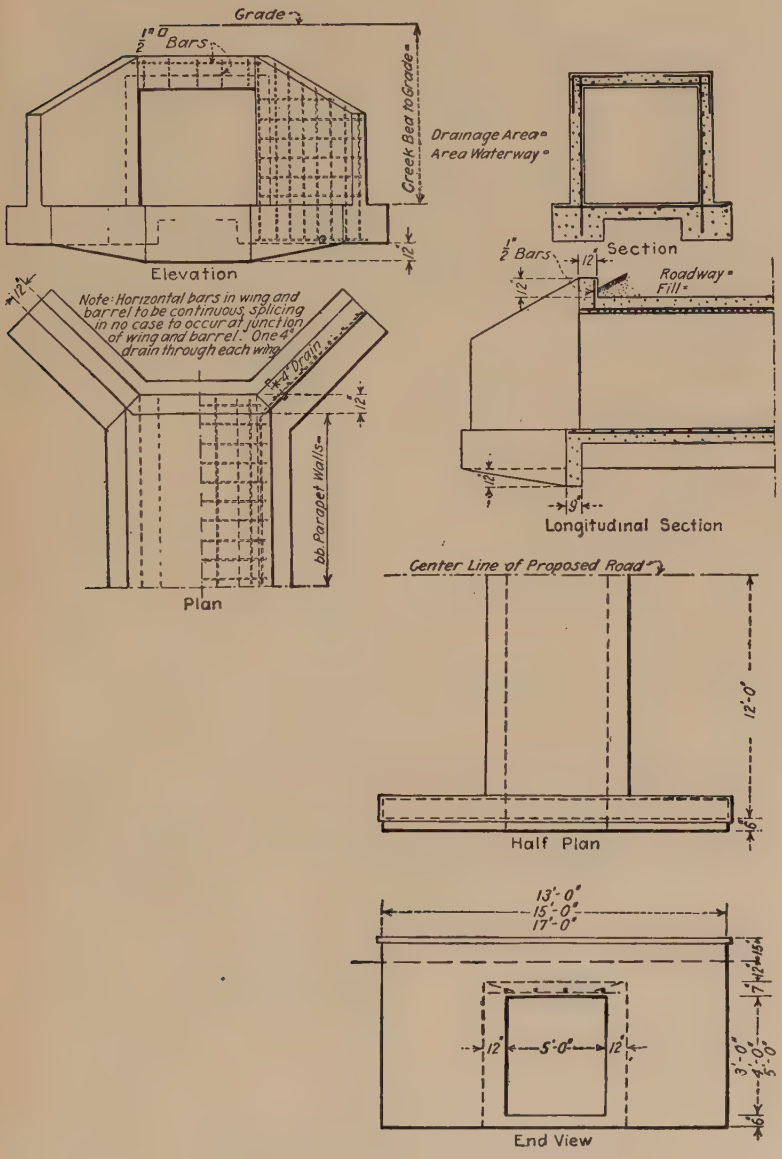


FIG. 11.—Plans for concrete box culverts.

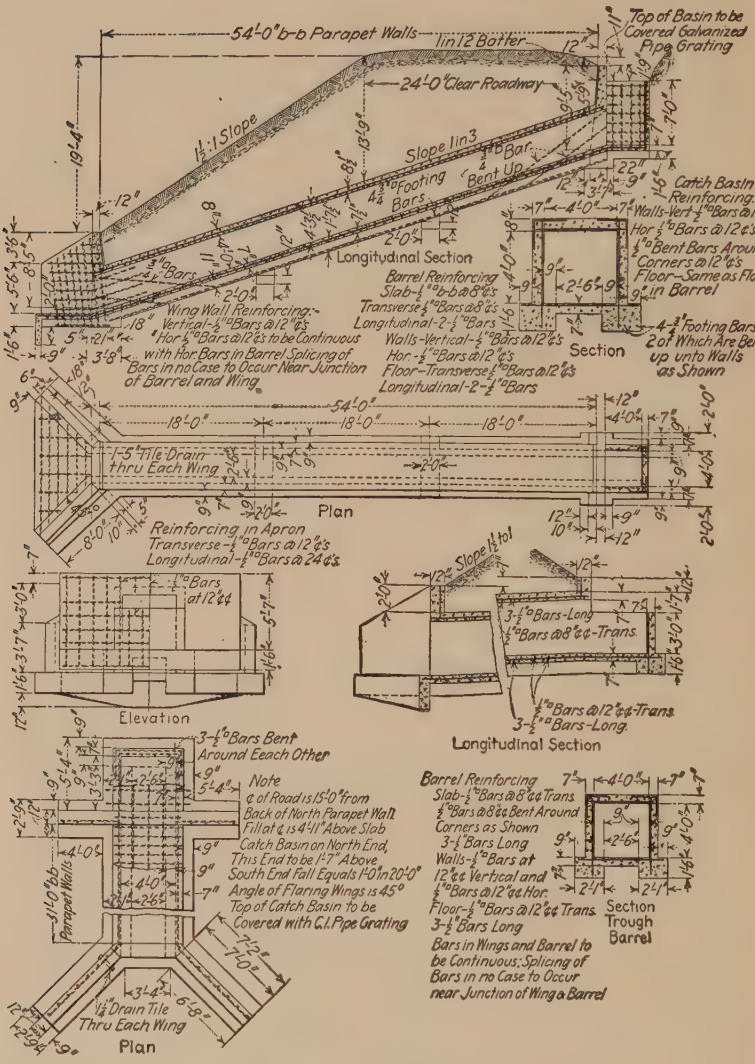

54'-0" b-b Parapet Walls
1 in 12 Batter
Top of Basin to be Covered Galvanized Pipe Grating
24'-0" Clear Roadway
1½:1 Slope
Slope 1 in 3
Footing Bent Up
Catch Basin Reinforcing:-
Walls-Vert-½"ø Bars @ 12"c's
Hor ½"ø Bars @ 12"c's
½"ø Bent Bars Around Corners @ 12"c's
Floor-Same as Floor in Barrel
Longitudinal Section
Barrel Reinforcing
Slab-½"ø b-b @ 6"c's
Transverse ½"ø Bars @ 8"c's
Longitudinal-2-½"ø Bars
Walls-Vertical-½"ø Bars @ 12"c's
Hor-½"ø Bars @ 12"c's
Floor-Transverse ½"ø Bars @ 12"c's
Longitudinal-2-½"ø Bars
Section
4-¾"ø Footing Bars 2 of Which Are Bent up unto Walls as Shown
Wing Wall Reinforcing:-
Vertical-½"ø Bars @ 12"c's
Hor ½"ø Bars @ 12"c's to be Continuous with Hor Bars in Barrel, Splicing of Bars in no Case to Occur Near Junction of Barrel and Wing
1-5"ø Tile Drain thru Each Wing
Plan
Reinforcing in Apron
Transverse-½"ø Bars @ 12"c's
Longitudinal-½"ø Bars @ 24"c's
Elevation
Slope 1½ to 1
3-½"ø Bars-Long
½"ø Bars @ 8"c-c-Trans.
½"ø Bars @ 12"c-c-Trans.
3-½"ø Bars-Long.
Longitudinal Section
3-½"ø Bars Bent Around Eeach Other
Note
℄ of Road is 15'0" from Back of North Parapet Wall
Fill at ℄ is 4'11" Above Slab
Catch Basin on North End, This End to be 1'-7" Above South End Fall Equals 1'-0" in 20'-0"
Angle of Flaring Wings is 45°
Top of Catch Basin to be Covered with C.I. Pipe Grating
1½" Drain Tile Thru Each Wing
Plan
Barrel Reinforcing
Slab-½"ø Bars @ 8"c-c Trans.
½"ø Bars @ 8"c-c Bent Around Corners as Shown
3-½"ø Bars Long
Walls-½"ø Bars at 12"c-c Vertical and ½"ø Bars @ 12"c-c Hor.
Floor-½"ø Bars @ 12"c-c Trans.
3-½"ø Bars Long
Bars in Wings and Barrel to be Continuous; Splicing of Bars in no Case to Occur near Junction of Wing & Barrel
Section Trough Barrel

FIG. 12.—Plans for drop inlet culverts.

TYPES OF CULVERTS

Reinforced Concrete.—Reinforced concrete is a desirable material for culverts because the form of the culvert can be readily adapted to the site. The materials are obtainable in almost every locality, and can readily be transported to the site because they can be carried in small units. The resultant structure is proof against injury from the elements, and the strength of the culvert can be adapted to the location. Figures 11 and 12 show a few typical plans for concrete culverts.

Pipe Culverts.—Culverts are made of clay pipe, cast-iron pipe, concrete pipe, and, to a limited extent, from steel pipe riveted into appropriate lengths. The load on a pipe in a ditch is made up of two factors; (1) the earth fill, and (2) the portion of the weight of traffic units that is carried to the culvert.

Table IV may be employed for estimating the load on pipe culverts or box culverts when the culvert is laid or constructed in a trench of a depth greater than the height of the culvert so that the berm of undisturbed soil extends a few inches above the top of the culvert. It should be noted that the breadth of the ditch and not the diameter or span of the culvert is to be used in taking the load from the table.

When a culvert is constructed in the open and then covered by a fill deposited in the usual manner as would be the case when a trestle is replaced by a fill, or when a truss bridge is replaced by a box culvert and fill, the load on the culvert is considerably greater than given in Table IV. No authentic data are as yet available to show exactly what the dead load on the culvert will be in these cases, but for fills up to 20 ft. in height, the following is a fair approximation. First determine the load on the culvert assuming B in Table IV to be the outside diameter or the total breadth of the culvert, then multiply this quantity by $1\frac{1}{2}$. This will give values slightly too high for shallow fills and slightly too low for deep fills, based on what now seems to be the probable actual load in such cases.

The proportion of the weight of traffic units that is carried to culverts through fills of varying depths depends upon many factors, such as the character of the filling material, the condition of the fill as regards water content, the extent to which it is compacted and the manner of the application of the load. This subject has been and still is a matter of investigation, and no con-

TABLE IV.[1]—APPROXIMATE ORDINARY MAXIMUM LOADS ON DRAIN TILE AND SEWER PIPE IN DITCHES FROM COMMON DITCH FILLING MATERIALS. IN POUNDS PER LINEAR FOOT

H = Height of fill above top of pipe	B = Breadth of ditch, at top of pipe									
	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.
	Partly compacted damp top soil. 90 lb. per cubic foot					Saturated top soil. 110 lb. per cubic foot				
2 ft.	130	310	490	670	830	170	380	600	820	1,020
4 ft.	200	530	880	1,230	1,580	260	670	1,090	1,510	1,950
6 ft.	230	690	1,190	1,700	2,230	310	870	1,500	2,140	2,780
8 ft.	250	800	1,430	2,120	2,790	340	1,030	1,830	2,660	3,510
10 ft.	260	880	1,640	2,450	3,290	350	1,150	2,100	3,120	4,150
	Dry sand. 100 lb. per cubic foot					Saturated sand. 120 lb. per cubic foot				
2 ft.	150	340	550	740	930	180	410	650	890	1,110
4 ft.	220	590	970	1,360	1,750	270	710	1,170	1,640	2,100
6 ft.	260	760	1,320	1,890	2,480	310	910	1,590	2,270	2,970
8 ft.	280	890	1,590	2,350	3,100	340	1,070	1,910	2,820	3,720
10 ft.	290	980	1,820	2,720	3,650	350	1,180	2,180	3,260	4,380
12 ft.	300	1,040	2,000	3,050	4,150	360	1,250	2,400	3,650	4,980
14 ft.	300	1,090	2,140	3,320	4,580	360	1,310	2,570	3,990	5,490
16 ft.	300	1,130	2,260	3,550	4,950	360	1,350	2,710	4,260	5,940
18 ft.	300	1,150	2,350	3,740	5,280	360	1,380	2,820	4,490	6,330
20 ft.	300	1,170	2,420	3,920	5,550	360	1,400	2,910	4,700	6,660
22 ft.	300	1,180	2,480	4,060	5,800	360	1,420	2,980	4,880	6,960
24 ft.	300	1,190	2,540	4,180	6,030	360	1,430	3,050	5,010	7,230
26 ft.	300	1,200	2,570	4,290	6,210	360	1,440	3,090	5,150	7,460
28 ft.	300	1,200	2,600	4,370	6,390	360	1,440	3,120	5,240	7,670
30 ft.	300	1,200	2,630	4,450	6,530	360	1,440	3,150	5,340	7,830
Infinity	300	1,210	2,730	4,850	7,580	360	1,450	3,270	5,820	9,090
	Partly compacted damp yellow clay. 100 lb. per cubic foot					Saturated yellow clay. 130 lb. per cubic foot				
2 ft.	160	350	550	750	930	210	470	730	1,000	1,240
4 ft.	250	620	1,010	1,400	1,800	340	840	1,330	1,870	2,370
6 ft.	300	830	1,400	1,990	2,580	430	1,140	1,900	2,630	3,410
8 ft.	330	990	1,720	2,500	3,250	490	1,380	2,360	3,360	4,400
10 ft.	350	1,110	2,000	2,920	3,880	520	1,570	2,760	3,980	5,270
12 ft.	360	1,200	2,220	3,320	4,450	540	1,730	3,100	4,560	6,050
14 ft.	370	1,280	2,410	3,650	4,950	560	1,850	3,410	5,050	6,760
16 ft.	370	1,330	2,570	3,950	5,400	570	1,940	3,660	5,510	7,440
18 ft.	380	1,380	2,710	4,210	5,810	570	2,020	3,880	5,930	8,060
20 ft.	380	1,410	2,830	4,450	6,180	580	2,090	4,070	6,280	8,610
22 ft.	380	1,430	2,920	4,640	6,500	580	2,140	4,240	6,610	9,130
24 ft.	380	1,450	3,000	4,820	6,800	580	2,180	4,380	6,910	9,590
26 ft.	380	1,470	3,060	4,980	7,080	580	2,210	4,500	7,160	10,010
28 ft.	380	1,480	3,120	5,100	7,310	580	2,240	4,610	7,380	10,430
30 ft.	380	1,490	3,170	5,230	7,530	580	2,260	4,700	7,590	10,780
Infinity	380	1,520	3,410	6,060	9,480	580	2,340	5,270	9,360	14,620

[1] Engineering Experiment Station, Ames, Iowa, p. 46, *Bull.* 31.

clusive data are available. Designs based on the following assumptions have proven adequate, but eventually a more rational distribution will be deduced.

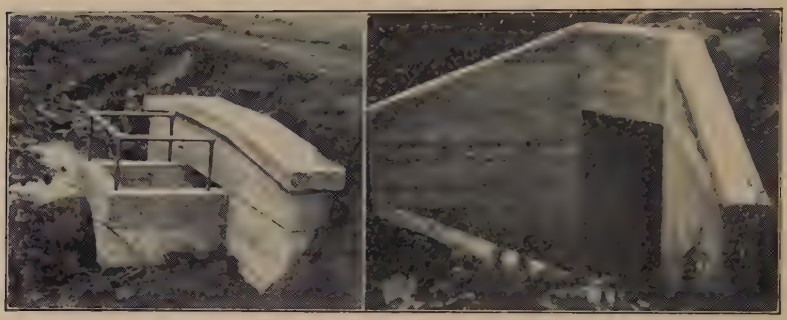
The percentage of the live load carried to the culvert may be assumed to vary from 100 per cent for fills of 1 ft. to zero for fills of 10 ft. This refers to the portion of the weight on one wheel or the roll of a power roller. Estimate the dead load (weight of fill) from Table IV and add to the dead load in pounds per foot of length of culvert the proper percentage of actual live load per foot of length and assume this to be uniformly distributed over the 1-ft. length of culvert. This applies to culverts built in trenches. For culverts over which fills are built, estimate the dead load as provided in the preceding paragraphs and then add the proper percentage of live load.

This emphasizes the necessity for care in the use of sectional pipe, especially under shallow fills. The pipe should be carefully bedded and concrete should be employed for bedding except on the most stable soil. The joints should be close and should be filled with cement mortar. The back-filling should be well tamped, especially at the sides of the pipe.

Headwalls.—It has long been the practice to construct headwalls or bulkheads at each end of a pipe culvert. This is an unnecessary expense in most instances and adds to the cost of lengthening the culvert if the fill is widened at some later date. It is better practice to make the culvert long enough to project about 2 ft. from the fill and to omit the headwall. In some instances the stream approaches the culvert at such an angle that a headwall is needed to prevent erosion or undercutting but in such cases the headwall should be designed to fit the slope of the fill and need not extend much above the top of the culvert barrel. Headwalls that tend to restrict the roadway should be avoided.

Figure 13 shows some designs of pipe culverts and headwalls, and Fig. 14 shows some views of completed culverts.

Paved Fords.—In many locations, particularly in prairie country, the streams are shallow and broad and have an insignificant flow except in flood seasons, when they may carry a large volume of water flowing in a comparatively thin sheet of considerable width. The cost of bridges or culverts of sufficient capacity for the flood flow is entirely out of proportion to the utility of such structures. An economical solution of this problem consists in constructing a paved ford across the flood-water



(*a*) (*b*)

(*c*)

FIG. 13.—Typical concrete culverts.

FIG. 14.—Typical pipe culverts.

channel of the stream, with a few concrete posts to serve as markers for the edge of the pavement if it is long or obscured. If there is constant flow a culvert under the ford can be constructed to care for the ordinary flow. If the stream is a dry run, except for a few weeks a year, no culvert is needed.

IV. CONTROL OF EROSION

General Problem.—Wherever precipitation is considerable or where it comes at a very high rate, erosion is sure to occur, and no small part of the problem of design of drainage facilities has to do with minimizing the tendency of flowing water to carry away the soil.

Two systems of controlling erosion are available and all works intended to control erosion employ one or the other of these methods, and often the two are employed in combination. The first system is one in which drainage channels are lined with concrete, rubble, planking or some similar material which will carry water with very slight erosion. The second employs the principle that the quantity of soil carried by flowing water increases with the velocity of the water and that, consequently, quiescent water will deposit any solid matter it may have carried. In applying this principle, drainage channels are so designed that a low velocity results and erosion is thereby reduced to a negligible factor.

Controlling Erosion of Ditches.—Where open ditches are designed for a velocity exceeding 2 ft. per second, erosion will be a factor that is not to be neglected. The simplest method of controlling erosion is to provide a succession of weirs across the ditch, thereby insuring a succession of pools of quiescent water at times of minimum flow. In a comparatively short time, soil will be deposited above each weir to the level of the top thereof, and erosion of the side ditch will be effectually checked. Just below each weir a small amount of erosion will occur but if the weirs are sufficiently close together such erosion as occurs will not be troublesome. The difference in the elevations of the top of successive weirs should not exceed 3 ft.

The weir may be constructed of plank or of masonry and the top should be about 6 in. lower at the middle than at the ends so that the water will not flow around the ends, but will flow over the middle part of the weir. The weir should extend 2 ft. into

the back slope of the ditch and the end toward the roadway should extend to the edge of the traveled way.

When the grade of the ditch is in excess of 5 per cent the cost of the weirs will be such that it will usually be economical to provide a paved gutter the entire length of the hill. Such gutters are constructed of cobblestones carefully set in place and grouted with cement mortar, or are constructed of portland cement concrete. Various designs are used and the capacity will of necessity vary with the amount of water to be carried. This method of controlling erosion is advisable only when the road area between gutters is paved with some material that resists erosion, otherwise erosion of the road between the gutters is likely to become so serious as to materially increase the cost of maintaining the surface.

It is often desirable to combine the pavement for the area between gutters with the gutter so that in reality the entire road surface is a drainage channel and at times of heavy storms will have great capacity. At times of slight flow the gutters will carry the water.

At some point near the bottom of the hill the water must be taken from the gutters to earth channels, which are usually at a somewhat lower level. Whatever method of controlling erosion may have been used for the ditch, the transition channel must be carefully designed. One method commonly employed is to carry the water through the transition channel in a concrete gutter carefully aligned so that the water will readily follow it. Another method is to take the water from the ditch directly into a masonry catch basin and from there carry it in a tile to a proper outlet. This method is not advantageous if large quantities of water must be handled, because of the size of catch basin and tile required.

Controlling Erosion of Side Slopes.—The erosion of the side slopes of cuts and fills becomes a serious problem if any considerable amount of water flows down them. There is no way to prevent the water that actually falls on the slopes from running down the slopes, but the water that falls on the land adjacent to a cut is diverted by means of a ditch above the upper edge of the slope of the cut and is carried to a suitable outlet. If this is not possible it is concentrated at one or two points and then brought down the slope of the cut in a plank flume.

The water that falls on the roadway of a fill section of road will cause troublesome erosion if allowed to flow down the slopes at will, and to prevent this it is diverted by means of a ridge of

earth at the top of the slope and carried to paved channels or flumes that lead down the slope to the lower level.

Erosion can be greatly retarded on slopes of cuts and fills if a rank growth of grass can be secured. This is difficult to secure because of lack of moisture during some seasons of the year. Few grasses will prove hardy enough to live on the slopes, but Western wheat grass and Hungarian brome grass will survive in most of the humid areas, but of course no growth can be maintained in the arid and semi-arid regions.

Control of Stream Erosion.—To a limited extent the drainage structures on a highway can be utilized to minimize stream erosion adjacent to the road. In some instances the drainage area for a culvert consists of a few acres, and a tile may be used instead of a culvert. The tile may be extended by landowners to drain the area above the culvert thereby limiting erosion.

In other instances the culvert may be set high enough to cause considerable sedimentation above it thereby retarding stream erosion. The drop-inlet type of culvert is particularly effective for such a purpose.

Problems

1. Give the class a map showing the drainage area tributary to a stream that passes through a culvert under a highway and have them compute the area of waterway for the culvert.
2. Give the class a section of the plan for grading an earth road involving a deep cut and a high fill and ask them to design the ditches and other devices that are to be used for drainage and to minimize erosion.
3. Ask the class to design a paved surface for the road in Problem 2, with especial reference to drainage and the control of erosion.
4. A section of east and west highway 1,100 ft. long has a grade of 0.3 per cent toward a drainage ditch 12 ft. deep that crosses the highway. The land on the north side has a slight slope toward the highway and on the south side has a slight slope away from the highway. The maximum cut on this section of road was 1.6 ft., measured from the profile of the center line and the maximum fill 1.9 ft. Design a system of tile drains for the section of highway.

CHAPTER IV

ECONOMICS OF HIGHWAY GRADES

The general acceptance of the stage construction, or progressive road improvement plan as a fundamentally sound policy requires greater emphasis to be placed on the first step in such a plan; that of designing longitudinal grades. Longitudinal grades constitute the most nearly permanent feature of the whole construction program, and a complete analysis of the factors governing this feature of design is therefore warranted.

In railroad location the longitudinal grades are established almost wholly with relation to the *characteristics of traffic* which is anticipated on the line. In the highway field the road builder and the operators of the traffic are entirely disassociated and the highway department is not directly accountable for the cost of operation of the vehicles on the roads which it builds. Accordingly, the highway engineer has too often based his design on the physical characteristics of the site and construction features of the proposed improvement. Recognition of the need for providing economical transportation service is the outstanding development in the new era of road building. The effects of grades, distance, curvature, and type and condition of road surface on the cost of operation are gradually becoming recognized as the basic considerations in road design.

The designing of longitudinal grades involves the consideration of certain characteristics of traffic and certain physical factors such as drainage, access to adjacent property, appearance, and safety. Maximum grades will generally be established with a view to facilitating the movement of traffic. Grades below the maximum rate will be fixed with a view to keeping the earthwork costs as low as possible.

Characteristics of Traffic.—Automobiles are designed with a view to securing mobility and that quality designated as "performance," which really means that the engine has the power to produce a high rate of acceleration. The full power of the engine is seldom used on level roads, being in reserve for use on

bad roads, hills, and for acceleration. The engine, being of the throttle-governed, 4-cycle type, is most efficient at full throttle at a speed selected by the designer, generally between 30 and 40 mi. per hour. On hills that are not so steep as to slow the speed below that which is most efficient, the engine is somewhat more efficient than at the same speed on level roads because the hill gives the engine a favorable load. Commercial vehicles such as trucks and busses are sometimes provided with excess engine power as are automobiles, but the heavier commercial vehicles do not have great reserve power, and depend upon the use of the change gears to a greater extent than do automobiles. Like the automobile engine, the commercial vehicle engine is most efficient under full load at a certain speed, but full load is reached on lower rates of grade than those that give full load to the automobile engine. Up to a certain rate of grade, a hill creates a condition favorable to economical operation of a gas-engine driven vehicle. The exact rate of ascending grade that is the upper limit of this favorable operating condition depends upon the power of the engine and the gear ratios, or more properly speaking, upon the tractive effort that can be exerted by the driving wheels. This is generally expressed in terms of tractive effort, in pounds per ton of weight of vehicle.

The tractive effort in high gear may be insufficient to permit the vehicle to operate under certain conditions of road surface or grade, and change gears are provided to take care of this situation. But operation of the vehicle when driven through the change gears is less economical than when it is driven in high gear, because of the additional friction and lower engine efficiency. Therefore, when a hill requires a change in gears during the ascent, power waste is introduced.

Plus Grades.—The maximum economical rate of grade for an automobile to ascend is one that will permit ascent in high gear at, or near, the ordinary road speed, 35 to 45 miles per hour. This rate of grade, when determined, is the maximum economical plus grade for an automobile highway.[1]

Likewise, the maximum economical grade for a commercial vehicle to ascend is one that will permit the ascent at the proper speed without shifting gears. The grade of a highway can never be exactly correct for both classes of traffic, nor can it be correct

[1] Agg, T. R., "The Economics of Highway Grades," Iowa Eng. Exp. Sta., *Bull.* 65, Vol. 21, No. 39, Feb. 28, 1923.

for all classes of commercial vehicles. A compromise of all the divergent requirements must be effected and that can be accomplished acceptably only when the exact effect of grade on the cost of transportation is thoroughly understood.

If the average tractive effort, in high gear, intermediate gear, and low gear, of the vehicles that make up the traffic on a highway have been determined, it will then be possible to adapt the highway design to the vehicle, so that operation thereof will be most economical, in view of the known volume of each class of vehicles that use the road.

Tractive effort is available to overcome tractive resistance and the effect of grade. If, from the tractive effort of a vehicle in high gear, the tractive resistance for that vehicle is subtracted, the remainder, divided by 20, is the maximum economical grade for that vehicle, provided momentum effects are not taken into account. The rate of grade thus determined may require so much earth work that the cost will not be justified by the volume of traffic on the highway, but an estimate of the situation must begin with the theoretical maximum grade.

The maximum economical grade for ascending vehicles may be calculated as follows:

$$P_p = \frac{T}{20} - \frac{R}{20} \tag{7}$$

P_p = maximum economical plus grade (vehicle ascending) in feet per 100 ft. of road.

T = the maximum tractive effort of the engine at the desired speed in high gear, in pounds per ton of weight of vehicle and load.

R = the tractive resistance of the vehicle on the proposed type of road at the desired speed, in pounds per ton of weight of vehicle and load.

Momentum Effects.—Since the automobile is so mobile, it lends itself readily to a method of operation that takes advantage of momentum effects in hill climbing. This is merely another way of saying that hill climbing is facilitated by "taking a run" for the hill. If the vehicle slows down when ascending a hill, a certain amount of kinetic energy is transformed into the work of climbing the hill. Commercial vehicles have the same mobile characteristics as automobiles, but to a lesser extent. Assume that the speed of the vehicle at the beginning of the ascent is

V_1 ft. per second and that when the ascent has been completed the speed has been reduced to V_2 ft. per second.

The loss in kinetic energy in foot-pounds is,

$$E_k = \tfrac{1}{2}m(V_1^2 - V_2^2) + \tfrac{1}{2}I(w_1^2 - w_2^2) \qquad (8)$$

The quantity $\tfrac{1}{2}m(V_1^2 - V_2^2)$ will be recognized as the change in kinetic energy of translation due to the change in speed. The quantity $\tfrac{1}{2}I(w_1^2 - w_2^2)$ is the corresponding change in kinetic energy of rotating parts, which cannot be calculated readily, but has been determined experimentally. For ordinary computations involving automobiles, it may be taken as 5 per cent of the kinetic energy of translation, and for commercial vehicles 10 per cent. The total change in kinetic energy takes place in the length of the hill, which should be measured along the actual profile, but for the purposes of the highway engineer may be taken as the distance given by the profile stationing, since the error thus introduced is negligible. The average force contributed by the change in kinetic energy of an automobile over

TABLE V.—CHARACTERISTICS OF THE COMPOSITE AUTOMOBILE

Speed range in miles per hour	Tractive effort on the several gears in pounds per ton		
	High	Second	Low
25 to 40	185	400	600

Relative fuel mileage on the various gears..... { high gear, 26 / second gear, 20 / low gear, 14

CHARACTERISTICS OF COMPOSITE COMMERCIAL VEHICLE

Speed range in miles per hour high gear	Tractive effort on the several gears in pounds per ton			
	High	Third	Second	Low
15 to 25	130	160	250	380

the length of road in which the speed changed from V_1 to V_2 is therefore

$$\text{Average Force} = \frac{\frac{m}{2}(1.05)(V_1^2 - V_2^2)}{L} \qquad (9)$$

This may be written

$$\text{Average Force} = \frac{70}{L}(S_1^2 - S_2^2) \tag{10}$$

Where S_1 and S_2 represent the speeds in miles per hour corresponding to V_1 and V_2, and E_k the kinetic energy per ton of weight.

By adding the grade effect of momentum as given in Equation (10) to Equation (7), we have

$$P_p = \frac{T}{20} - \frac{R}{20} + \frac{3.5}{L}(S_1^2 - S_2^2) \tag{11}$$

In any location where density of traffic, topographical features, and traffic regulation permit taking advantage of momentum effects, the maximum grade for automobiles is determined from Equation (11). It will be noted that the maximum grade will decrease with L, for any assumed limits of speed.

Where it is apparent that momentum effects cannot be realized by the bulk of the traffic the maximum grade can be determined from Equation (7).

Minus Grades.—When a vehicle is descending a hill, power from the engine will be used to maintain speed if the rate of grade is below a certain minimum. It will coast at uniform speed without power from the engine when the rate of grade is just right and it will accelerate without power from the engine if the rate of grade is great enough.

The ideal grade for the descending vehicle is the one that will permit the vehicle to descend without using power or the brakes and without exceeding the speed fixed by regulations or considerations of traffic safety.

The grade P_m, which will permit the vehicle to coast at constant speed is equal to $R/20$, where R is the tractive resistance for the particular road, vehicle, and speed, in pounds per ton.

By analogy with Equation (11), it will be apparent that if momentum effects are considered this grade can be increased by the grade equivalent of the momentum permitted, which for automobiles is $\frac{3.5}{L}(S_1^2 - S_2^2)$, in per cent of grade.

Therefore,

$$P_m = \frac{R}{20} \tag{12}$$

or

$$P_m = \frac{R}{20} + \frac{3.5}{L}(S_1^2 - S_2^2). \tag{13}$$

In this connection it should be noted that S_1 is used to designate the speed in miles per hour at the *beginning* of an ascent and at the *end* of the descent. The reason is obvious.

The maximum minus grade for economical automobile operation may be determined from Equation (12) if no momentum effect is to be considered, and from Equation (13) if momentum effects are to be taken into account. The second S_1 and S_2 will be determined by the same considerations involved in arriving at maximum plus grades.

Grades for Commercial Vehicles.—The foregoing discussion has been based on the characteristics of automobiles, but precisely the same analysis applies to commercial vehicles, except that the ratio of the kinetic energy of rotating parts to that of translation is estimated to be 10 per cent instead of 5. With that change the formulas for grades for commercial vehicles become

$$P_p = \frac{T}{20} - \frac{R}{20} + \frac{3.65}{L}(S_1^2 - S_2^2), \tag{14}$$

$$P_m = \frac{R}{20} + \frac{3.65}{L}(S_1^2 - S_2^2). \tag{15}$$

Rate-of-grade Diagrams.—The four equations developed in connection with plus and minus grades may be converted into diagrams that are convenient for use in establishing grades, by calculating the per cent grade for various lengths of hill, after inserting appropriate values for T, R, and L in the several equations.

In Table V are average values of T for typical vehicles of 1927 and 1928 design. Typical grade diagrams are given in Figs. 15 and 16, the data upon which they are based being indicated in the diagram. These are applicable only to grades for high type road surfaces.

Effect of Excessive Grades.—If a motor vehicle is driven up a grade, enough fuel must be used to lift the vehicle some height H. When the vehicle descends such a grade, all of the potential energy will be utilized if the grade is not too steep, but if the grade is in excess of the economical maximum the potential energy cannot all be utilized because of necessity for the use of the brakes. Moreover, the ascent may be possible only by using some gear other than high gear, if the rate of grade is excessive, and consequently more fuel is used in lifting the vehicle than

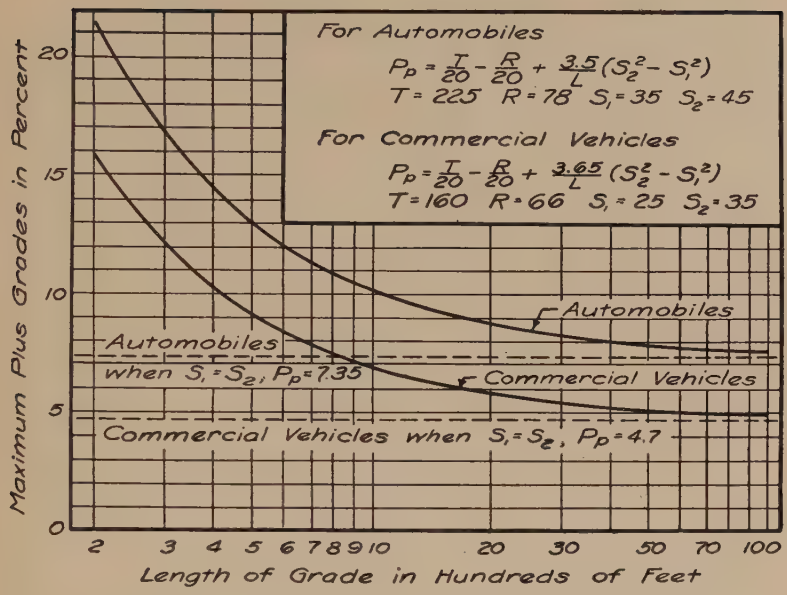

For Automobiles
$P_p = \frac{T}{20} - \frac{R}{20} + \frac{3.5}{L}(S_2^2 - S_1^2)$
$T = 225$ $R = 78$ $S_1 = 35$ $S_2 = 45$
For Commercial Vehicles
$P_p = \frac{T}{20} - \frac{R}{20} + \frac{3.65}{L}(S_2^2 - S_1^2)$
$T = 160$ $R = 66$ $S_1 = 25$ $S_2 = 35$
Automobiles
Automobiles when $S_1 = S_2$, $P_p = 7.35$
Commercial Vehicles
Commercial Vehicles when $S_1 = S_2$, $P_p = 4.7$
Maximum Plus Grades in Percent
0
5
10
15
20
2 3 4 5 6 7 8 9 10 20 30 50 70 100
Length of Grade in Hundreds of Feet

FIG. 15.—Diagram for determining maximum plus grades.

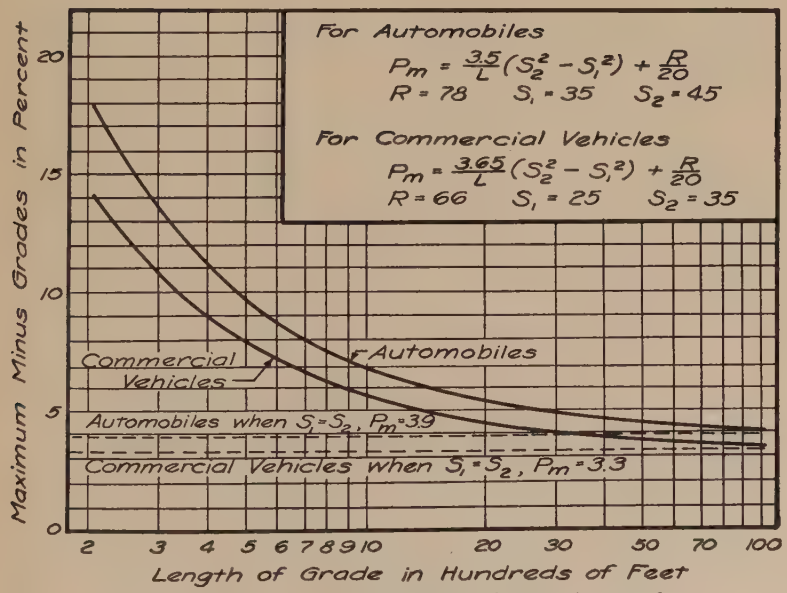

For Automobiles
$P_m = \frac{3.5}{L}(S_2^2 - S_1^2) + \frac{R}{20}$
$R = 78$ $S_1 = 35$ $S_2 = 45$
For Commercial Vehicles
$P_m = \frac{3.65}{L}(S_2^2 - S_1^2) + \frac{R}{20}$
$R = 66$ $S_1 = 25$ $S_2 = 35$
Commercial Vehicles
Automobiles
Automobiles when $S_1 = S_2$, $P_m = 3.9$
Commercial Vehicles when $S_1 = S_2$, $P_m = 3.3$
Maximum Minus Grades in Percent
0
5
10
15
20
2 3 4 5 6 7 8 9 10 20 30 50 70 100
Length of Grade in Hundreds of Feet

FIG. 16.—Diagram for determining maximum minus grades.

would have been required for an equal height on a rate of grade equal to or below the economical maximum. Let M be the ratio of the fuel consumption on any gear other than high to that required for the same work in high gear. Then the actual effect of lifting the vehicle through the height H by the use of a gear other than high is the same as lifting it a height MH by the use of high gear. To get this relation into terms applicable to highway grades, it may be expressed thus:

$$E = W(MH - h) \tag{16}$$

where

E = the energy equivalent of the fuel consumed because of excessive grade, in foot-pounds.
H = the total rise in feet as shown by the profile, which can be expressed in terms of an average grade P.
h = the total rise in feet when the grade has been reduced to P_p.
W = the weight of the vehicle in pounds.

It will be apparent that in some cases h and H will be equal and the rate will be reduced by increasing the length of the hill, which may be accomplished in some cases without changing the length of the route.

Since $H = PL$ and $h = P_pL_p$, Equation (16) may be written

$$E = W(MPL - P_pL_p) \tag{17}$$

in which

L = the length of grade having the rate P, and height H.
L_p = the length of grade having the rate P_p.

With gasoline weighing 5.9 lb. per gallon, testing 19,000 B.t.u. per pound, and costing C dollars per gallon, and an engine having an over-all efficiency of 15 per cent, the cost of the energy represented by E may be computed as follows:

$$\text{Cost} = \frac{(C)(E)}{(19{,}000)(777.6)(5.9)(.15)} = \frac{W(MPL - P_pL_p)C}{(19{,}000)(777.6)(5.9)(.15)}. \tag{18}$$

The annual traffic ascending the hill may be represented by V_a the annual traffic ascending the hill in millions of tons.

The annual cost of the excessive plus grade for the traffic V_a is

$$D_a = \frac{(C)(V_a)(1{,}000{,}000)(2{,}000)(MPL - P_pL_p)}{(19{,}000)(777.6)(5.9)(.15)}. \tag{19}$$

Since this is an annual cost, the saving to traffic due to the elimination of the cost of excessive grades may be capitalized on an appropriate basis to ascertain what sum could justifiably be expended for grade reduction. It is probably unwise to extend the period of assumed benefit indefinitely because of the uncertainties that exist with reference to the kind and quantity of highway traffic in the future. If it is assumed that these benefits will surely continue for 25 years and that money can be borrowed at 4 per cent interest, then the justifiable expenditure for reducing a specific grade is the present worth of an annuity of D_a dollars running for 25 years. On that basis

$$S_a = 24CV_a(MPL - P_pL_p), \tag{20}$$

S_a = the justifiable expenditure in dollars for grade reduction to the appropriate economical plus grade.
C = the cost of gasoline in dollars per gallon.
V_a = the annual traffic in millions of tons ascending the grade.
M = a factor representing the relative fuel consumption in high gear to the consumption for the gear used on the grade P.

Excessive Minus Grades.—In the nomenclature employed in the foregoing discussion, a "plus grade" is one that a vehicle ascends. Obviously then, any hill is a plus grade for the traffic in one direction and it is a "minus grade" for the traffic in the opposite direction. The energy expended in raising the vehicle on grades that are too steep has already been evaluated but since the most economical minus grade is always a lower rate than the economical plus grade, it remains to determine the justifiable expenditure for reducing the grade to any rate less than the economical maximum plus grade.

By a process of analysis identical with that employed in the discussion of plus grades, the justifiable expenditure for reducing grades for descending traffic can be shown to be

$$S_d = 24CV_a(P_pL_p - P_1L_1) \tag{21}$$

in which P_1 is any rate of grade between P_m and P_p, and L_1 is the length of the grade P_1. This equation holds true so long as P_1 is either equal to or greater than P_m.

Procedure in Establishing Grades.—A very casual inspection of the profile of a proposed improvement will indicate which hills

need to be checked from the standpoint of maximum grades, and the length and average rate of grade on the existing profile can be jotted down. A grade diagram has presumably been prepared on the basis of the proposed type of improvement. The volume of automobile and commercial vehicle traffic that will probably use the road has been estimated.

With these preliminaries out of the way, the correct plus grade for each class of traffic is noted on the profile for each hill where the existing grade is in excess of the economical maximum.

The sum that can be justifiably expended to reduce each grade to the theoretically correct rate for each class of traffic is then estimated from the Equation (20). A rough estimate of the probable cost of the earthwork necessary to reach the proposed maximum grade is next prepared by establishing a preliminary grade line for the hills in question. If in any case the cost of earthwork thus estimated is materially in excess of the justifiable expenditure, a special study is made of that location with a view to relocation or some modification of the grade line that will reduce the cost of earthwork.

It is apparent that estimates of the value of grade reduction cannot be exact, but they do give positive information in most of the projects of major importance. The final decision will be based on the financial considerations, the importance of safety and convenience, and sometimes the drainage and topographical situation (danger of land slips, probability of excessive snow accumulations, etc.). On secondary roads the financial consideration is likely to govern more frequently than on trunk-line roads.

The second step is to ascertain which grades are in excess of the theoretically economical minus grades and to lay trial grades on them on the basis of ordinary engineering considerations such as sight distance, appearance, and drainage, being careful not to make any of the proposed grades less than the theoretical minus. The saving to traffic by these grade changes is then estimated from Equation (21). This revision does not affect a saving to ascending traffic.

The designer is now in position to judge as to the efficiency of his preliminary grade line. If the cost of earthwork is to be materially in excess of the value to traffic, there is every probability that the quantity of earthwork should be reduced by further study of the grades.

It should be noted that separate studies must be made for automobile traffic and commercial vehicle traffic. In rough country, this sort of analysis involves a great deal of work but the possibilities of saving in earthwork costs are also manifold. In other cases, the study will be applied only to a few critical grades.

In the great preponderance of highway-design problems, the grades are fixed on the basis of the requirements for automobile traffic. The tonnage of commercial vehicle traffic seldom reaches an amount that will materially affect the financial situation. In a few instances, however, it will be wise to go beyond the economic considerations to reduce delay to commercial vehicles and thus minimize congestion.

Experimental Coefficients.—In estimating the effect of various grade conditions upon the cost of operating self-propelled vehicles it is necessary to use certain quantities that are determined from the mechanical design of the vehicle and from measurements that have been made in the course of various investigations in the field of highway grades. None of these are established with finality as yet but those that appear herein are the best available at the present time.

Tractive Resistance.—The term "tractive resistance" is usually interpreted to mean a hypothetical force whose line of action is parallel to the road surface and the longitudinal axis of the vehicle and whose magnitude is equal to the summation of the components in that line of all external forces acting upon the vehicle when it is traveling on a level surface. It may simplify the discussion of tractive resistance if its several components are considered separately.

A. Rolling Resistance.—When a wheel rolls over a road surface there is distortion of that surface. If the surface is of a yielding or plastic substance, a rut is formed. If the surface is elastic, it deflects slightly under the load, but subsequently resumes its original position. In the former case considerable road surface resistance is encountered; in the latter, very little.

In either case, the tire of the vehicle is distorted in the region of contact with the road surface and some power loss results. This is dissipated in the form of heat and mechanical deterioration of the tire.

The above constitute the factors of rolling resistance, but neither varies according to a simple law. The minimum rolling

resistance is a value equivalent to the power loss in the tire. For pneumatic tires this is about 22[1] lb. per ton of weight on the tire and for solid tires about 30[2] lb. per ton of weight on the tire.

The rolling resistance of a rubber tire which is caused to roll on a smooth dynamometer drum or on a circular track of any

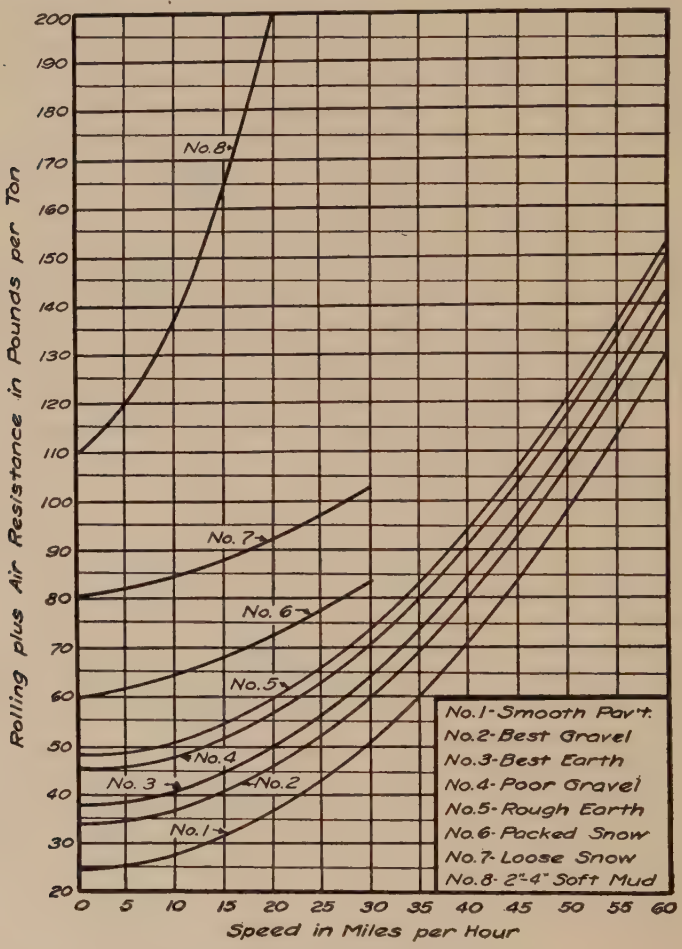


FIG. 17.—Typical tractive resistance curves.

practicable diameter is a fairly definite quantity which can be measured quite accurately by determining the power loss in the

[1] HOLT, W. L., and P. L. WORMELEY, "Dynamometer Tests of Automobile Tires," *Tech. Paper* 240, U. S. Bur. Standards, Sept. 24, 1923, p. 567.

[2] LOCKWOOD, E. H., "Chassis Friction Losses," *Jour. S. A. E.*, November, 1922, p. 415.

tire for a period of time during which all conditions surrounding the test are held constant.

When the tire is mounted on the wheel of a self-propelled type of vehicle and drawn over a road surface, or is caused to coast over that surface, the resistance to the motion of the vehicle consists not only of the equivalent of the power loss in the tires but also the effects of air and wind, wheel-bearing friction, impact, and distortion of the road surface. The power loss in the tire is reasonably uniform under a fixed set of conditions, but when a vehicle is moving along a highway the conditions that influence rolling resistance are continually changing.

The curves in Fig. 17 show the magnitude of rolling plus air resistance for a typical automobile on several kinds of roads. Since no two roads of any type are exactly alike and since the ratio of air resistance to weight varies for vehicles of different types and weights, it naturally follows that the resistance-speed curves obtained with a variety of vehicles on any one type of road will seldom coincide. On the contrary they are likely to form a band, the width of which reflects the effects of several variables enumerated above.[1]

B. Air Resistance.—The retarding effect of the air upon self-propelled vehicles is generally recognized and comprises a considerable part of the total tractive resistance. Air resistance may be computed from the formula

$R_a = CAV^2$, where

R_a = the total air resistance in pounds.

A = the projected cross-section of the vehicle in square feet.

V = the speed of the vehicle relative to the air in miles an hour.

C = an experimental coefficient.

A value of 0.0025 for the constant C was established by extensive wind-tunnel researches[2] under the direction of Prof. L. E. Conrad at the Kansas State Agricultural College. Some recent investigations[3] at Yale University indicate that the constant

[1] Agg, T. R., "Tractive Resistance of Automobiles," Iowa Eng. Exp. Sta., Ames, Iowa, *Bull.* 88, Vol. 26, No. 70, May 2, 1928.

[2] Conrad, L. E., "Wind Resistance of Motor Vehicles," *Public Roads*, Vol. 6, No. 9, November, 1925, pp. 203–206.

[3] Lockwood, E. H., "Air Resistance of Automobiles," a paper presented at the NE Sec. S. A. E., New Haven, Conn., Nov. 13, 1928, and included in the *Proc.* 8th Annual Conference, Highway Research Board, Washington, D. C., 1928.

C may be expected to vary between 0.0019 and 0.0025 for automobiles of recent design.

Tractive resistance may be considered to consist of two groups of resistance, thus

$$R_t = R_r + R_a \qquad (22)$$

where

R_t = total tractive resistance in pounds per ton.
R_r = rolling resistance in pounds per ton.
R_a = air resistance in pounds per ton.

R_r may be expected to vary from about 22 lb. per ton of weight of vehicle to about 45 lb. per ton for roads of all types in good condition. It will reach 100 lb. per ton and more on mud roads and snow.

Grades for Animal-drawn Vehicles.—In populous districts in the United States, animal-drawn vehicles constitute a negligible part of the traffic on rural highways, but there are other areas where that class of traffic must be considered in designing highway grades.

Let P_1 = the number of pounds pull an animal can exert steadily for several hours, if the load is momentarily relieved at irregular intervals.
P_2 = the number of pounds pull an animal can exert for short intervals of time.
n = the number of animals used to draw a load.
R = the rolling resistance for the vehicle and road surface under consideration, per ton of gross weight of vehicle.
T = the normal load in tons for 0.0 grades.
G = the maximum permissible grade in per cent.

Then

$$T = \frac{nP_1}{R}, \text{ and}$$

$$G = \frac{n(P_2 - P_1)}{20T}. \qquad (23)$$

If conditions surrounding the project permit an exact determination of load and the weight of animals, then a more exact

formula for maximum grade will take account of the work required to lift the weight of the animals, as follows:

$$G = \frac{n(P_2 - P_1)}{20(T + W)}$$

where W is the total weight in tons of the animals used to draw the load.

If the grade is more than 500 ft. long, it will be necessary to rest the animals about every 100 ft. beyond the first 500, when the maximum rate of grade is used.

For most draft animals P_1 should not exceed about one-tenth of the weight of the animal, and P_2 should not exceed one-third the weight of the animal, except that for distances not greater than 100 ft. it may be taken at one-half the weight of the animal.

The values of R applicable to vehicles with steel tires may be taken from Table VI. This table is made up of values selected from various reports of investigations of the subject and includes only dependable average values.

TABLE VI.—AVERAGE TRACTIVE RESISTANCE OF ROADWAYS

(Applicable only to the average animal-drawn vehicle)

SURFACE	TRACTIVE FORCE POUNDS PER TON
Earth packed and dry	100
Earth dusty	106
Earth muddy	190
Sand loose	320
Gravel good	51
Gravel loose	147
Cinders well-packed	92
Oiled road, dry	61
Oiled road, wet	108
Macadam, very good	38
Macadam, average	46
Sheet asphalt	38
Asphaltic concrete	40
Vitrified brick, new	56
Wood block, good	33
Wood block, poor	42
Cobblestone	54
Granite tramway	27
Asphalt block	52
Granite block	47

Problems

1. The profile of an existing road across a sharp ridge shows 1,800 ft. of +9.1 per cent grade and 2,050 ft. of −6.4 per cent grade and the plans

provide for a high-type pavement to be constructed. The traffic on the highway averages 1,500 automobiles and 40 commercial vehicles per day. What grades should the engineer attempt to secure for this hill? What expenditure for grading would be justifiable in order to reduce the hill to the recommended grades?

2. The grades on a highway that is to be graded and graveled range in length from 300 to 700 ft. and the traffic is made up almost wholly of automobiles. What ruling grade should the engineer adopt? What maximum grade?
3. A city is planning extensive grade changes, possibly including tunnels, to afford better grades for the arterial streets connecting industrial districts in the various parts of the city. What grades should be adopted as the maximum? What sum could be afforded to spend for each 1-ft. reduction of excessive grades, for a traffic of 10,000,000 tons per annum?

CHAPTER V

THE DESIGN OF RURAL HIGHWAYS

Highway design has not been reduced to an exact science nor can it be said, in general, that any particular design is the one best suited to a specific location. Differences in minor details and minor differences in the essential features characterize the designs developed by competent engineering organizations. There are certain fundamental principles that are quite generally recognized as being the basis of good design, but considerable latitude is allowable in adapting the design to the particular situation (which may be topographical, financial, or political) so long as the design does no violence to those basic principles. To a considerable extent, highway design offers an opportunity for the exercise of originality and good engineering judgment in incorporating recognized principles into a plan that does not necessarily follow stereotyped standards.

Width of Right-of-way.—The width of right-of-way required for present purposes can be determined when the design for the cross-section has been completed and will depend largely upon the width required for the traveled way and the prevalence of cuts and fills. There are two widths that have in the past been followed in establishing the right-of-way widths for public highways, the one being 40 ft., which prevails widely in the eastern and southern part of the United States, and 66 ft., which prevails in the middle west. In the far west both widths have been established more or less indiscriminately. It is exceedingly difficult to secure more than 20 ft. of traveled way on a 40-ft. right-of-way, if adequate ditches are to be provided and if there are to be any cuts or fills exceeding about 5 ft. in height or depth. Where traffic requires more than 20 ft. of width, including the surfaced portion and the shoulders, a right-of-way more than 40 ft. wide will generally be necessary. For trunk-line highways in populous areas there should be ample provision for future widening, and it is difficult to predict what may be required.

In certain areas in England steps have recently been taken to increase the width of right-of-way from about 85 to 125 ft.

In laying out the Ideal Section of the Lincoln Highway in Lake County, Indiana, the right-of-way width was fixed at 100 ft. In the vicinity of Detroit, Mich., steps have recently been taken to increase the right-of-way widths to 125 and 150 ft. on several arterial highways. The engineer must be liberal in his allowance for future development in populous areas.

The first impression may be that the need for such extreme width of right-of-way will not arise for many years and then in only a few areas, which is perhaps true. But if it ever develops and has not been anticipated, the cost of securing the extra width will be very great because of the structures of various kinds that will have to be moved or destroyed. This contingency has already arisen on certain highways in Illinois, Michigan, and Pennsylvania.

It has been suggested that options on the additional right-of-way be secured now and that the present owner be allowed to continue to use the land until it is needed for highway purposes. Meanwhile no structures would be allowed to encroach on the ultimate right-of-way.

The 66-ft. right-of-way permits the construction of a paved surface 20 ft. wide with ample shoulders and ditches even where cuts of considerable depth are required.

The problem of design is to determine the width needed for present purposes and to estimate the eventual developments so far as it is possible to do so. The requirements of the present can be determined as soon as the design for the cross-section has been completed.

The principles of design are most readily presented by considering in turn each of the elements of a highway and the fundamental considerations upon which the design of each element is based. The elements of highway design are:

1. The cross-section.
2. The alignment.
3. The profile, or grade line (Chap. IV, in part).
4. The drainage system (Chap. III).
5. The system of signs and markers.
6. Safety features, such as guard fence.
7. Accessories.

I. THE CROSS-SECTION

The cross-section of a highway is shown in Fig. 18. Certain parts of this typical section may be omitted in some designs, but

it shows all the elements that should be considered when developing the design. If any are omitted, it will be after due consideration of the need for that element on a particular highway. Obviously, supplementary drainage ditches and guard fences are required only at certain places. Likewise, tile drains and storm-water inlets. The cross-section of a highway consists of several independent units, the design of each being developed in harmony with the other parts but on the basis of the particular function of the part.

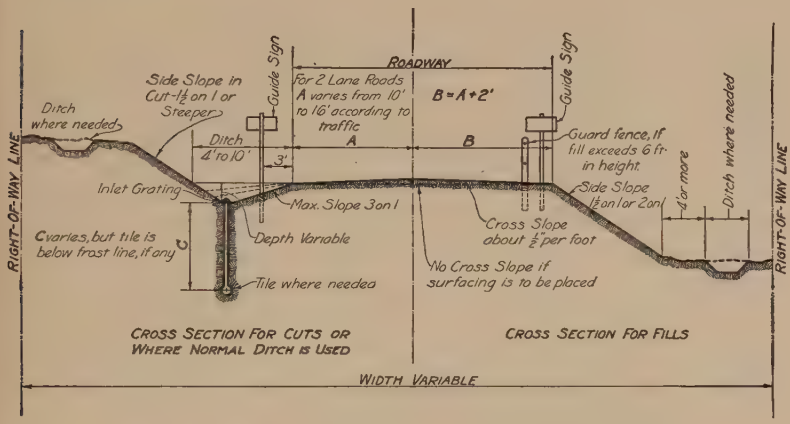

Guide Sign
ROADWAY
Guide Sign
Side Slope in Cut-1½ on 1 or Steeper
For 2 Lane Roads A varies from 10' to 16' according to traffic
B=A+2'
Ditch where needed
Ditch 4' to 10'
A
B
3'
Guard fence, if fill exceeds 6 ft. in height
Inlet Grating
Max. Slope 3 on 1
Side Slope 1½ on 1 or 2 on 1
4' or more
Ditch where needed
RIGHT-OF-WAY LINE
C varies, but tile is below frost line, if any
C
Depth Variable
Cross Slope about ¼" per foot
No Cross Slope if surfacing is to be placed
Tile where needed
RIGHT-OF-WAY LINE
CROSS SECTION FOR CUTS OR WHERE NORMAL DITCH IS USED
CROSS SECTION FOR FILLS
WIDTH VARIABLE

FIG. 18.—Showing elements of a highway cross-section.

THE ROADWAY

The portion of the road intended for the use of vehicular traffic is called the "roadway," and a portion of it may be provided with a wearing surface of some type or the natural soil may be used. So far as the cross-section is concerned, the roadway presents two basic problems: width and cross slope.

Width.—The width of the roadway is fixed by the amount of traffic it is necessary to accommodate. It is usually stated that for each traffic lane there should be a width of 10 ft. This, however, assumes that the traffic consists principally of self-propelled vehicles, which is correct in most areas of the United States where upwards of 90 per cent of the traffic is of this class. If, however, the predominating traffic is animal-drawn, then the width of a traffic lane would ordinarily be less than 10 ft., probably about 8 ft.

The minimum width of roadway is in general that which will provide for two lanes of traffic, or for motor traffic, 20 ft. But if only this width were available on embankments, it would cause traffic to use the surface for the full width of the embankment, which is not desirable. The edges of the roadway on embankments are likely to be somewhat irregular due to settlement and erosion and, when wet, are seldom firm enough to carry traffic. For these reasons a greater width of roadway is provided on embankments than on sections in cut, or where the normal side ditch is provided. There is no standard for this extra width but experience indicates that it should be not less than 2 ft. along each edge. Where two lanes only are to be provided, then the minimum width of roadway should be 20 ft. in a normal cross-section with the usual side ditches, and 24 ft. on embankments. Such a design would be suitable for roads that carry a moderate volume of traffic, perhaps up to 150 vehicles per day. Vehicles would not use the outer 5 or 6 ft. of the roadway except when passing other vehicles, which would not occur frequently on a road of this class.

When the traffic is sufficient in volume to require a wearing surface two lanes wide, there is passing traffic to consider on only one side of the lane (the left-hand lane in the United States), and it is not necessary to provide a width of 10 ft. per lane, but there are few who consider less than 9 ft. per lane as adequate. Consequently, the standard two-lane wearing surface is generally either 18 or 20 ft. wide. But the designer must take into account two other factors that are injected into the problem when a wearing surface is to be constructed on the roadway. The first of these is the necessity for providing enough width of berm alongside the wearing surface to make certain that the edge of the wearing surface is adequately supported. The second is that vehicles will sometimes be compelled to stop along the road for various reasons and there should be a berm alongside the wearing surface of sufficient width to permit such vehicles to draw out of the traffic lane, which requires a berm width of at least 6 ft. Preferably the berm should be at least 8 ft. wide. The minimum width of 6 ft. is sufficient to afford support to the edge of the wearing surface, in fact, 4 ft. is adequate in most locations.

Traffic Capacity.—The traffic capacity of a road may be estimated as follows:

Let N = the number of traffic lanes.
S = the average speed of traffic in miles per hour.
C = the spacing, or headway, of the vehicles in feet.
Q = the total traffic in vehicles per hour, assumed to be about equally dense in each direction.
L = the average length of vehicle in feet.

Then

$$Q = \frac{5280NS}{L + C}. \tag{24}$$

The clearance C must be a safe distance, which is one that will permit a following vehicle to avoid colliding with a leading vehicle which stops quickly for some reason. This may be but 10 or 15 ft. when the speed is low but will be greater at higher speeds. A safe clearance allowance to use in computations is a distance equal to half the distance required to bring a vehicle to a stop.

It will be found that one may safely assume a negative acceleration of 6 ft. per second for most road surfaces, except when icy or covered with greasy slime.

A. N. Johnson, Dean of Engineering, at the University of Maryland, made extensive observations of traffic on the Washington-Baltimore highway,[1] including an airplane survey[2] and is inclined to believe that the actual clearance between vehicles under normal driving conditions will vary approximately as the $\frac{4}{3}$ power of the speed. His researches indicate actual spacings ranging from the 1.3 to the second power of the speed. Observations made by the author on various boulevards and trunk-line highways indicated the same tendency but developed the fact that traffic appears to bunch behind some slow-moving vehicle and the clearances were exceedingly variable. Nevertheless, it seems quite clear that the clearance increases materially with speed and the assumption that clearance increases as the square of the speed is probably safe for estimating traffic capacity. Introducing that factor into Equation (24) it becomes

$$Q = \frac{5280NS}{L + 0.09S^2}. \tag{25}$$

[1] Johnson, A. N., "Traffic Study Proves Two-lane Road Widths Sufficient," *Eng. News-Record*, Vol. 86, No. 23, June 9, 1921, p. 989.

[2] Johnson, A. N., "Photographic Traffic Survey," *Proc.* Eighth Annual Meeting, Highway Research Board, Washington, D. C., 1928.

Computation by the foregoing method indicates the maximum traffic capacity of a highway.

There are so many uncertainties in the behavior of traffic and the conditions that interfere with the free flow of the vehicles are so numerous that maximum capacity is seldom sustained for any considerable period. Some records of actual traffic counts indicate that the theoretical maximum discharge is sometimes reached but is seldom continued for any considerable period of time. Traffic surveys seem to point to 8,000 vehicles per day as the maximum for a two-lane highway, but at the peak load the discharge may reach as many as 1,000 vehicles per lane per hour.

If the computations of traffic capacity show that more than two lanes are required, four should be provided, since, as a rule, a three-lane road is unsatisfactory. Obviously, fractional increases in the number of lanes do not particularly increase the traffic capacity, although such increases may add to safety on busy roads.

It is noticeable that a three-lane traffic way does increase the traffic capacity over that of a two-lane, although it does not actually provide a free lane for traffic in either direction. The increase in traffic capacity is due to the facility with which fast-moving traffic can pass the slower-moving traffic that is going in the same direction. The central lane of a three-lane road is really used almost exclusively as a passing track, but when the traffic approaches saturation this third lane is of little use to the traffic in either direction.

When more than two lanes are provided, the vehicles traveling in all but the two outer lanes will have traffic lanes on either side and the full 10 ft. of width should be provided for all of the interior lanes. The two outer lanes may be reduced in width to 9 ft. if necessary. It is preferable to avoid doing so.

Cross Slope.—The roadway must be provided with cross slope for drainage, except in arid regions. In the normal design, drainage ditches are provided along each side of the roadway, which is constructed with a convex surface and is said to be crowned.

The difference in elevation between the edge of the roadway and the highest part thereof is the "total crown." The *total crown* divided by the distance in feet from the edge to the highest part is the "rate of crown." The longitudinal line at the highest

part of the roadway is the "crown line" and in normal cross-sections is at the middle of the roadway.

The rate of crown is fixed as a compromise between two conflicting requirements. The greater the cross slope, the better the drainage, and it is very desirable that the storm water run off the roadway quickly, especially when the wearing surface is of some absorbent material such as earth, gravel, sand-clay, or the like. But the greater the cross slope, the more the tendency for vehicles to slide sidewise when the surface is slippery. To compromise these divergent considerations with reference to cross slope, it is customary to hold the rate of crown to the minimum consistent with acceptable drainage of the wearing surface. The usual maximum is about $\frac{3}{4}$ in. per foot for fairly dense natural soils, $\frac{1}{2}$ in. for gravel and sand-clay types and $\frac{1}{4}$ in. for impervious surfaces. A good working rule for all non-absorbent surfaces is that the total crown should be not more than $\frac{1}{75}$ of the width and not less than $\frac{1}{100}$ of the width, when the crown line is in the middle. The equivalent rates of cross slope are to be followed for unsymmetrical cross-sections.

Superelevation.—When a vehicle is traveling in a curved path on a horizontal plane the centrifugal force tends to cause the vehicle to slide sidewise and away from the center of curvature. The intensity of the centrifugal force may be calculated from the familiar equation

$$F_1 = \frac{MV^2}{R} = \frac{WV^2}{gR} \tag{26}$$

Where F_1 = the centrifugal force in pounds.

M = the mass of the vehicle = $\frac{\text{weight in pounds } W}{32.2}$.

V = the tangential velocity of the vehicle in feet per second.

R = the radius of curvature in feet.

If the vehicle is standing, or moving in a straight line, on a plane that is inclined at an angle Θ with the horizontal, there is a force tending to cause the vehicle to slide or roll down the plane. The magnitude of this force for a vehicle weighing W lb. is:

$$F_2 = W \tan \theta. \tag{27}$$

Sliding, because of centrifugal force or the inclination of the plane, is opposed by the friction between the tires and the surface.

The magnitude of this resistance is equal to the normal pressure between the tires and the surface, multiplied by the coefficient of friction for the tires on that surface. When dealing with self-propelled vehicles, account must be taken of the fact that the driving wheels usually slide before the others, due to the slippage resulting from the driving effort.

To add to the safety in driving on horizontal curves the road surface, including the berms or shoulders, is constructed with the cross slope rising from the inside of the curve for the entire width of the surface, that is, instead of being crowned, it is superelevated. Animal-drawn traffic may be disregarded in the design of superelevation and the weight assumed for the vehicle may be considered instead of the normal pressure between wheels and road, since for the rates of superelevation employed in practice the two are so nearly of the same magnitude.

The theoretical superelevation required for any horizontal curve, when no account is taken of the effect of friction, may be calculated by assuming that F_1 and F_2, Equations 26 and 27, are to be equal; hence there is to be no tendency for the vehicle to slide in either direction.

Then

$$\tan \theta = \frac{V^2}{gR}. \tag{28}$$

In order to reduce this relation to terms readily applied in practice, the following are introduced:

e = the superelevation in feet per foot of width.
S = speed in miles per hour.
g = 32.2.
R = radius of curvature to the center line of the pavement, in feet.

In these terms, the superelevation formula becomes

$$e = 0.067\frac{S^2}{R}. \tag{29}$$

The effect of friction between tires and road surfaces may be introduced as follows:

Let p = the percentage of the weight that is carried by the rear wheels of the vehicle.
f = the coefficient of friction between the tires and the road surface.

Then

$$W \tan \theta = \frac{WV^2}{gR} - pWf$$

and

$$e = 0.067\frac{S^2}{R} - pf. \qquad (30)$$

Equation 30 is convenient for estimating the conditions that will exist on a curve that has less than the theoretical superelevation and is of low frictional resistance because of ice or some other coating on the road surface.

TABLE VII.—SUMMARY OF COEFFICIENT OF FRICTION

Average coefficients of friction between tires and *dry* road surfaces, sliding in the line of travel. Each value average of 40 determinations.

Surface	Four wheels, starting	Sliding, uniform	Two wheels, starting	Sliding, uniform
P. C. concrete, 2 years old	0.77	0.74	0.89	0.81
P. C. concrete, 5 years old, greasy	0.74	0.68	0.96	0.89
Asphaltic concrete	0.85	0.80	0.87	0.79
Bitulithic	0.73	0.67	0.69	0.61
Wood block	0.84	0.79	0.82	0.75
Brick, monolithic	0.88	0.84	0.91	0.82
Brick, sand filled	0.86	0.82	0.87	0.79
Brick, asphalt filled	0.95	0.89	0.85	0.75
Gravel	0.65	0.61	0.75	0.65
Earth	0.68	0.65		

Average coefficients of friction between tires and *wet* road surfaces, sliding in the line of travel. Each value average of 40 determinations.

Surface	Four wheels, starting	Sliding, uniform	Two wheels, starting	Sliding, uniform
P. C. concrete, 2 years old	0.75	0.71	0.96	0.85
P. C. concrete, 5 years old, greasy	0.82	0.76	0.64	0.54
Asphalt concrete	0.86	0.82	0.86	0.82
Bitulithic	0.72	0.67	0.73	0.72
Wood block	0.73	0.48	0.81	0.60
Brick, monolithic	0.65	0.60	0.60	0.54
Brick, sand filled	0.66	0.60	0.62	0.53
Brick, asphalt filled	0.71	0.65	0.81	0.75
Gravel	0.63	0.57	0.79	0.68
Earth	0.59	0.52		

The coefficients of friction between tires and road surfaces that have been measured at Ames[1] are summarized in Table VII.

Drainage Ditches.—The cross-section usually adopted for highways naturally lends itself to placing the ditches at the side of the traveled way. In those instances where considerable ditch capacity must be provided, the ditch is an element of danger and the transition from the traveled way to the bottom of the ditch should not be too abrupt. A slope of 3 on 1 is about right, and for a ditch 2 ft. deep there will be required a width of 6 ft., plus the back slope width. The back slope of the ditch is usually made as steep as the natural soil will stand, which is about 1½ on 1. The width required for back slope will be variable, depending upon the depth of cut.

For fills, the side slope will be what the natural soil will stand when freshly deposited, which is about 1½ on 1 for most soils. Along the fills the drainage ditch will be on the low level, out a few feet from the toe of the slope.

The use of tile has been discussed in the chapter on drainage and need not be taken up here except to call attention to the fact that the layout of the tile system is a part of the problem of design in those instances where tile is needed.

II. ALIGNMENT

The general route of a road is fixed by the principles governing the establishment of the particular system of highways of which it is a part. The exact location of the sections of the highway between towns is a problem of engineering economics which is solved by an analysis of location inspections and surveys that are carried out as preliminaries to construction. So far as possible, an existing right-of-way is utilized but in many instances minor and some major relocations of the route will be necessary to secure correct alignment.

Four main considerations enter into the establishment of the final location: (*a*) directness; (*b*) grades; (*c*) safety; (*d*) esthetics.

Directness.—The location of a road is based on the desire to secure a connection between towns or districts. Generally there is no reason for improving any other than the shortest possible

[1] Agg, T. R., "Tractive Resistance of Automobiles and Coefficients of Friction of Pneumatic Tires," *Bull.* 88, Iowa Engineering Exp. Sta., Ames, Iowa, p. 27, 1928.

route. In studying the location, the question of shortening the route by means of relocations will present itself. When such proposed relocations do not involve questions of safety or grades, the justifiable expenditure for the relocation will be based on time- and cost-saving to vehicle operators.

The annual saving to traffic by virtue of the relocation can be estimated, to which is added the savings in cost of construction, and it may reasonably be assumed that the saving will extend over a considerable period of time, say 30 years. Some authorities would assume that the savings would continue indefinitely, but it is probably unwise to base expenditures on that assumption because of the uncertainties with reference to the nature of the traffic of the distant future. If 30 years be selected as the basis for computation, then the justifiable expenditure for shortening a route is the present worth of an annuity equal to the estimated annual saving, running for 30 years, the interest rate being that which is usual in public financing.

The items of automobile operating cost that are affected by mileage of travel aggregate about 4.5 cts. per mile for mixed traffic in 1928. Time is worth about 2.5 cts. per mile per vehicle and the total cost is therefore about 7 cts. per mile. The mileage cost for commercial vehicles is about 16 cts. per vehicle mile, including items such as the pay of drivers and the schedule value of time. In the absence of definite cost data applicable to the traffic involved in a specific problem, the general average ones may be used.

Grades.—There are two methods available for reducing the rate of grade on a highway. One is to reduce the height of the hill by excavating at the top, filling at the bottom, or by doing both; the other is to increase the length of the road thereby reducing the rate of grade. This latter method is employed in very hilly or mountainous country and the problem is solved by selecting the best alignment possible in view of the topographical limitations. The distance between terminals will generally be increased by relocations of this type and there is no way to avoid doing so.

When relocations for short distances are being considered with a view to avoiding unfavorable grades, the fact that increased distance means an increase in cost of transportation, must be taken into account. The saving brought about by reducing grades is to be balanced against the increased cost of distance,

and the decision as to the alignment to adopt will be determined by the economic facts thus deduced.

Safety.—Curves of short radius, high embankments, locations subject to landslips, grade crossings with other transportation lines, obscure intersections with other highways and similar physical and topographical features of a route contribute to accidents. Adjustments of alignment in the interest of greater safety are justifiable regardless of the effect upon distance. Many minor relocations are necessary to secure safety and these are adopted without special regard for the economic aspects of the problem.

Esthetics.—Wherever it is possible to locate a road so that travelers may enjoy beautiful scenery, it is well worth while. Sometimes major relocations are undertaken in order to traverse regions of natural beauty. With a little care in location beautiful vistas, imposing bridges, villages nestling in some wooded valley and similar inspiring scenery can be brought into the range of vision of those who traverse a highway. This is well worth the time and effort required.

HORIZONTAL CURVES

Wherever the topography permits, horizontal curves are designed to carry the traffic without the necessity for reducing speed, and preferably without introducing superelevation. The sharpest curve that meets the situation is the 3-deg. curve (radius = 1,910 ft.). If the curve is sharper, superelevation should be employed.

At intersections of highways, the right-of-way that was established when the road was originally laid out, is of insufficient width to permit long radius curves such as are now required, and additional right-of-way must be secured to permit the necessary relocation at these intersections. In general the new curve should be not more than a 7-deg. curve for trunk highways, and not more than a 12-deg. curve for secondary roads.

Easements.—The use of easement curves has not been common in highway practice but for any curve where superelevation is adopted the easement spiral is necessary to a neat and harmonious development of the curve where paved surfaces are constructed.[1] There is no theoretical basis for calculating the

[1] PRITCHETT, C. M., "Spiral Curves Cut Costs of North Carolina Road Work," *Eng. News-Record*, Vol. 93, No. 4, Nov. 13, 1924, p. 132.

length of the easement curve, but an empirical rule that is quite satisfactory is to make the length of the easement in feet equal to the total superelevation in feet, multiplied by 75.

Any suitable spiral is satisfactory[1] for the highway easement curve and its use will permit widening curves as desired and spiraling both sides of the pavement slab.

Width of Curves.—The roadway surface is usually widened on curves having a center-line radius of 750 ft. or less, the amount of the widening being based on empirical rules which rest on experience. There is no method whereby the amount of extra width can be computed exactly. The need for the extra width arises from two causes. In the first place, a vehicle actually requires a wider path on a curve than on a tangent. The extra width required decreases with an increase in the radius of the curve and is in no case a large factor. In the second place, the drivers of self-propelled vehicles have the habit of holding toward the inside of the curves and will often use the berm along the wearing surface, especially when the curvature is sharp. For these reasons, the wearing surface is widened on curves. The practice of state highway departments in this respect is indicated in Table VIII.

Most of the states employ Voshell's[2] rule for widening which is

$$W = 2[R - \sqrt{(R^2 - L^2)}] + \frac{35}{\sqrt{R}}. \qquad (31)$$

in which

W = widening, in feet.
R = radius of curve, in feet.
L = wheel base of vehicle, in feet (average 20 ft.).

III. VERTICAL CURVES

At those places where the rates of longitudinal grade change, the transition is made safe and sightly by introducing vertical curves at the summits and sags. In planning the grades for highways in hilly regions it is often advantageous to employ vertical curves almost to the exclusion of straight-line grades because of the saving in earthwork costs that can be effected

[1] Brown, J. M., and R. V. Newcomb, "Widening and Spiraling Highway Curves," *Eng. & Contr.*, May 7, and June 4, 1924, pp. 1003, 1234.

[2] Voshell, J. T., District Engineer, U. S. Bur. Public Roads, Chicago, Ill.

TABLE VIII.—STATE PRACTICES IN SUPERELEVATION AND EASEMENT OF CURVES[1]

State	Method of superelevating	Pitch of fully superelevated sections	Transition section and rate	Complete bank	Pavement cross-section on fully superelevated section	Extra width	
						Amount	Character
California mountain roads.	.....	¾ in. per foot, 75-ft. radius and under. ½ in. per foot, 75 to 100-ft. radius. ⅜ in. per foot, 100 to 150-ft. radius. ¼ in. per foot, 150 to 225-ft. radius. ⅛ in. per foot, 225 to 300-ft. radius.	Transition length 30 ft., one-half on tangent and one-half on curve, except on reverse curves, where it may be made as long as 50 ft.	.....	Uniform slope, thickness and width, except that when superelevation exceeds ¼ in. per foot and is toward the fill slope a curb 6 in. wide and 10 in. high is used on the lower edge.	2 ft. on 150-ft. radius and less, if pavement is less than 18 ft. wide.	
Indiana.....	Revolved on center line of surface as axis.[2]	½ in. per foot width, all curves.	Outer edge raised from 2 in. below elevation of center line at P. T. C. to 4½ in. above center line at P. C. and line on inner edge, 9 ft. from center line, lowered from 2 in. below elevation of center line at P. T. C to 4½ in. below at P. C.	Full bank P. C. to P. T.	Uniform slope edge to edge, and uniform thickness, P. C. to P. T. Uniform width. P. C. +50 to P. T. −50.	8 ft. for 30° curve. 8 ft. for 20° curve. 6 ft. for 15° curve. 4 ft. for 10° curve. 2 ft. for 5° curve. 1.6 ft. for 4° curve.	Uniform width P. C. +50 to P. T. −50. Transition 100 ft. long.

Michigan.....	Revolved on a line near inner edge of curve parallel to center line of unwidened pavement and one-half of the normal width of the pavement therefrom.	1 in. per foot width, 66 to 150-ft. radius. ¾ in. per foot width, 151 to 300-ft. radius. ⅝ in. per foot width, 301 to 450-ft. radius. ½ in. per foot width, 451 to 700-ft. radius.	P. C. −75 normal section. P. C. −50, ¼ normal superelevation. P. C. −25, ½ normal superelevation. P. C., ¾ normal superelevation. P. C. −25, full superelevation.	Full bank P. C. +25 ft. to P. T. −25 ft.	Uniform slope edge to edge, and uniform thickness; variable width.	6 ft. for 66 to 150-ft. radius. 5 ft. for 151 to 300-ft. radius. 4 ft. for 301 to 450-ft. radius. 3 ft. for 451 to 700-ft. radius.	Transition and widening obtained by using simple curve of longer radius on inside of curves.
New Jersey.....	Revolved on center line of surface as axis.	⅛ in. per foot width.	100-ft. easement section. Normal section at P. C. −100, one-half of full superelevation at P. C. −50, and crown largely eliminated.	Full bank P. C. to P. T.	Uniform slope edge to edge, uniform thickness, and uniform width.	.....	No widening.
New York.....	Revolved on center line of surface axes.[2]	1 in. per foot width up to 300-ft. radius 15/16 in. per foot width, 300 to 400-ft. radius. ⅞ in. per foot width, 400 to 550-ft. radius. 13/16 in. per foot width, 550 to 800-ft. radius. ¾ in. per foot width, 800 to 1,500-ft. radius. ½ in. per foot width, 1,500 to 2,500-ft. radius.	Zero at 85 ft. back of P. C. (300-ft. radius). Zero at 75 ft. back of P. C. (300 to 400-ft. radius). Zero at 65 ft. back of P. C. (400 to 550-ft. radius). Zero at 55 ft. back of P. C. (550 to 800-ft. radius). Zero at 45 ft. back of P. C. (800 to 1,500-ft. radius). Zero at 35 ft. back of P. C. (1,500 to 2,500-ft. radius). Transition on tangents.	Full bank P. C. to P. T.	.....	8 ft. for 300-ft. radius. 7 ft. for 300 to 400-ft. radius. 6 ft. for 400 to 550-ft. radius. 5 ft. for 550 to 800-ft. radius. 4 ft. for 800 to 1,500-ft. radius. 3 ft. for 1,500 to 2,500-ft. radius.	Uniform width P. C. to P. T. with transition on tangents.

[1] Public road.

[2] "Center line" referred to in Indiana, Pennsylvania, New York, Washington, and West Virginia is the center line of the unwidened curve, and not the center line of the curve after widening.

TABLE VIII.—STATE PRACTICES IN SUPERELEVATION AND EASEMENT OF CURVES[1]—Continued

State	Method of superelevating	Pitch of fully superelevated sections	Transition section and rate	Complete bank	Pavement cross-section on fully superelevated section	Extra width	
						Amount	Character
Ohio	Inside edge of pavement kept a uniform distance, equal to crown on tangents, below grade line.	0.042 ft. per foot width, 30° curve. 0.042 ft. per foot width, 4° curve. 0.032 ft. per foot width, 3° curve. 0.021 ft. per foot width, 2° curve. 0.011 ft. per foot width, 1° curve.	At P. C. −50 ft., normal crown. At P. C. −25 ft., pavement raised one-fourth total superelevation. At P. C., pavement raised one-half total superelevation. At P. C. +50 ft., use total superelevation.	Full bank P. C. +50 ft. to P. T. −50 ft.	Uniform slope edge to edge, and uniform thickness; uniform width, P. C. +50 to P. T. −50	8 ft. for 30° curve. 1 6 ft. for 4° curve, etc. .4-ft. for 1° curve.	Uniform width P. C. +50 ft. to P. T. −50 ft.; transition curves 100 ft. long, established by offsets.
Pennsylvania	Revolved on center line of surface as axis.[2]	½ in. per foot width for all curves, 50 to 300-ft. radius.	Spiral transition used on inside only. Rate and amount by special table.	Full bank between transition curves.	Uniform slope edge to edge, and uniform thickness, uniform width.	6.5 ft. for 50-ft. radius. 4.5 ft. for 100-ft. radius. 3 ft. for 200-ft. radius. 2.5 ft. for 260-ft. radius. 2 ft. for 300-ft. radius.	Spiral transition; uniform extra width between transition curves.
Washington	Revolved on center line of subgrade as axis.[2]	0.055 ft. per foot width, 40° curve. 0.0475 ft. per foot width, 20° curve. 0.035 ft. per foot width, 10° curve. 0.018 ft. per foot width, 3° curve.	At P. C. −50 ft. normal section; at P. C. one-half of total superelevation; at P. C. +50, full superelevation transition curve on inside edge of pavement only.	Full bank (P. C. +50 ft. to P. T. −50 ft.).	Uniform slope and thickness; width increases to P. C. +150 ft., then uniform to P. T. −150 ft.	Extra width equals the cube root of the degree of curvature to the nearest $\frac{1}{10}$ ft., the minimum used being 1.5 ft.	Zero at P. C. −50 ft. 10 per cent. of total at P. C. 59 per cent. of total at P. C. +50 ft. 87 per cent. of total at P. C. +100 ft. Total at P. C. +150 ft.

West Virginia.....	Revolved on center line of surface as axis.[2]	0.06 ft. per foot width, 75-ft. radius. 0.047 ft. per foot width, 125-ft. radius. 0.039 ft. per foot width, 175-ft. radius. 0.037 ft. per foot width, 200-ft. radius. 0.025 ft. per foot width, 400-ft. radius.	Superelevation at P. C. one-third total, and at P. C. +25 two-thirds total.	.....	Uniform slope edge to edge, and uniform thickness.	3 ft. for 75-ft. radius. 2 ft. for 125-ft. 1 ft. for 175-ft. radius. 0 ft. for 200-ft. radius. 0 ft. for 400-ft. radius.	Widening to be done by "mooning" on inside of curve.

[1] Public roads.

[2] "Center line" referred to in Indiana, Pennsylvania, New York, Washington, and West Virginia is the center line of the unwidened curve, and not the center line of the curve after widening.

thereby. There are few basic principles involved and it is a simple matter to adapt the vertical curve to the conditions of a specific design.[1]

Vertical Curves at Summits.—When two vehicles approach the top of a hill from opposite directions on a highway at least two lanes wide, there is no element of danger provided each is held to its proper lane and the drivers are able to see each other while they are still a reasonable distance apart. Measurements made for the author on a large number of cars of recent design verified the assumption that the line of sight of an automobile driver is about 5 ft. above the road surface. With that factor fixed, the curvature is readily computed for any desired sight distance. The problem then becomes one of determining what constitutes a reasonable sight distance but upon this point it is not easy to be specific. Perhaps a good basis for preliminary computations is to determine how much distance is required to bring a vehicle to a stop from the extreme road speed to be expected (if there is any such thing as a limit to speed, which seems doubtful). If the road surface permits a reasonable application of the brakes without starting a skid, a vehicle with four-wheel brakes could be stopped in about 250 ft. from a speed of 50 miles per hour (a not uncommon bus speed in 1928). This would indicate that about 500 ft. is the minimum sight distance for summits on busy trunk-line highways. On roads in the secondary system it is easy to deduce that a sight distance of 250 ft. is enough.

Whatever conclusion is reached with reference to minimum sight distance, the minimum radius of vertical curvature for summits is fixed thereby.

The circular arc is the correct form of curve to use because it insures the same sight distance whatever the relative position of the vehicles when they first sight each other. As a matter of construction convenience, the parabolic form of vertical curve is often employed and in most instances the two forms of curve are so much alike that it matters little which one is used. In other instances the parabolic grade line will require materially heavier grading. This can readily be checked in connection with a specific design.

[1] FURR, M. W., "Application of Vertical Curves to Highway Design," *Eng. News-Record*, Vol. 20, No. 96, May 20, 1926, p. 819.

Vertical Curves in Sags.—The minimum radius of vertical curvature in sags is fixed by the designer's judgment in the matter of appearance. Any curve that would be accepted from the standpoint of appearance will be of satisfactory riding quality. In most instances the vertical curves in sags are selected with a view of fitting the ground without excessive earthwork and are longer than would be required for other reasons.

Rolling Grade Lines.—In certain types of topography, notably where the highway leads over a succession of hills requiring grades upwards of 500 ft. long, a grade line is established that follows the existing topography quite closely. These are sometimes referred to as rolling grades. There is ample justification for the adoption of rolling grades in certain locations and the established grade line will be a succession of vertical curves selected to fit the existing topography as nearly as may be, but no vertical curve so adopted should lie outside the minimum radius needed to provide ample sight distance.

IV. BALANCING EARTHWORK

When grade lines are being established for proposed grade reductions an attempt is made to balance the quantities of earthwork so that all excavated material will be used in the embankment. In order to accomplish the balancing, the quantities of earth in cut and fill must be calculated and the probable amount of shrinkage, settlement, and subsidence estimated so that due allowance can be made for changes in volume resulting therefrom.

Computing Quantities.—In highway practice, the form of the final cross-section is such that the most convenient and accurate method of computing quantities of earthwork is by means of average end areas with cross-sections 100 ft. apart. Intermediate sections ("plus" cross-sections) are used for an occasional special condition, and in municipal work 50-ft. stations are frequently used for computing quantities. The criss-cross method and some other special ones are sometimes used for computing quantities, but most drafting rooms adhere to the end-area method.

Shrinkage and Swell.—When the volume of an embankment upon completion is less than the volume of the excavation from which the fill material was obtained, the difference is the *shrink-*

age. If the volume of the embankment is greater than the excavation from which the material was obtained, the difference is the *swell.*

Most soils are sufficiently porous that a cubic yard of excavated material will compact to somewhat less than 1 cu. yd. of embankment during the process of transporting and placing the soil in the embankment. The amount of shrinkage depends upon the nature of the soil, the size of the loads hauled from cut to fill, and the prevailing weather. The actual shrinkage of ordinary soils, therefore, varies under differing conditions from 0 to 30 per cent, or even more. The average, and quite general, allowance that is made for shrinkage of soils in balancing quantities is about 15 per cent.

Materials such as ledge rock, shale, and very hard-baked soils in desert regions will increase in volume when excavated and deposited in the usual manner. The extent of this increase in volume will be from 10 to 50 per cent, depending upon conditions. If an embankment is constructed of a mixture of soil and rock or shale, it will be necessary to determine whether the net result of mixing the two kinds of materials will be shrinkage or swell. This will depend upon the relative proportions of the two kinds of material and the nature of each.

Not only does the amount of earthwork shrinkage depend upon the sort of material that is being handled, but also on the method employed for performing the work. If it is handled in small loads by means of drag scrapers the shrinkage will be the maximum, other factors remaining constant. Earth that is handled by power shovels and transported in dump cars of several cubic yards capacity will shrink relatively little. Between these two extremes lie several methods of excavation that produce intermediate degrees of shrinkage.

In balancing quantities of earthwork it is therefore necessary to estimate the probable amount of shrinkage or swell and provide for it.

Settlement.—The decrease in height of an embankment that takes place subsequent to its completion is known as "settlement." Embankments of earth generally settle slowly for many months after they are first completed and the exact amount of settlement will vary with the nature of the fill material and the method of construction, as well as the weather conditions during and after construction. If the work is performed with

the usual earth-handling equipment, the settlement will generally be about 10 per cent. If the work happened to be performed under conditions that caused a high percentage of shrinkage the settlement will be slight. Rock fills, sand fills, and fills made up of mixtures of soil and a preponderance of rocky material will settle very little.

If a fill is expected to settle after completion, the finish grade stakes are set above grade to take care of the future settlement and the fill quantities must be computed on the basis of the allowance made. For ordinary soils that allowance is about 10 per cent, but a greater or lesser allowance will be made in many instances.

The amount of settlement can be minimized by constructing the embankment in horizontal layers, or "lifts," about 1 ft. thick, each being compacted with a power roller[1] before the next lift is placed. This method is not widely used in highway construction except when a pavement is to be placed on the fill immediately after completion. Rolled fills will generally settle a little no matter how carefully the work is done, and careless and inadequate rolling is of little value.

Subsidence.—If an embankment is placed on a soil of low supporting strength, such as is found in swampy or near-swampy locations, the weight of the embankment may be sufficient to exceed the supporting strength of the soil of the site. In such instances the entire embankment subsides slowly, compressing the underlying soil or squeezing it aside. Whether this action will take place in any doubtful case cannot be determined readily and the amount and rapidity of the subsidence can be judged only in the light of experience. Estimates of quantities of earth required for embankment on such sites are based on experience with similar sites and a guess at the exact condition of the site under consideration. Some means may be taken to hasten the subsidence so that the fill can be completed under a single contract.

Overhaul.—The estimates of the cost of excavation are generally based on some specified length of haul, and to the basic cost there is added a sum for each 100 ft. of haul distance in excess of the basic haul distance. The basic haul distance is generally called the "free haul," and is established by the terms of a

[1] LAMMIMAN, F. A., "Rolled Fill Earth Dam Constructed without Shrinkage," *Eng. News-Record*, Vol. 102, No. 10, Mar. 7, 1929, p. 388.

contract in accordance with the common practice in the locality where the work is to be done. In most of the highway contracts the free haul distance is 500 ft.

The average excess length of haul is known as "overhaul." Thus if the average haul distance were 700 ft. and the free haul 500 ft., the overhaul would be 200 ft.

The computation of overhaul is not a simple matter, since the actual haul varies with the stage of the work and the method of excavation adopted. Overhaul is most accurately specified and computed from the mass diagram and should be so calculated when reasonably precise results are desired. Contracts should always define clearly the manner in which overhaul will be computed.

A good rule to use for approximate computations of overhaul is as follows: Lay off half the free haul distance in each direction along the center line from the point where the profile passes from cut to fill. Find the centers of mass of the remaining embankment and cut, and subtract from the distance between the centers of mass the free haul distance. This will be the overhaul distance. Subtract from the total excavation the quantity lying within half the free-haul distance from the point where the profile passes from cut to fill. This is the quantity overhauled. Multiply the quantity of overhaul by the overhaul distance in hundreds of feet and by the station-yard price of overhaul to obtain the overhaul cost.

Guard Fences.—Guard fences are placed along embankments of a dangerous height, embankments on curves, and in other locations where it is desired to warn the traveler to be careful to stay on the traveled way. The value of the guard fence is partly psychological because it is not customary to build the fence of sufficiently rigid construction to retain a heavy vehicle that might strike the fence when traveling at speed.

Guard fences are of several types of each of which there are many designs. One type consists of planking and posts; another of wire fencing and posts, usually with a plank rail at the top; and a third consists of posts and wire cable.

Guide and Warning Signs.—There is a growing sentiment in favor of excluding from the right-of-way of the highway all signs except the official ones provided by the highway authorities. Of these signs there are four distinct classes: (*a*) guide signs, (*b*) caution signs, (*c*) danger signs, (*d*) route markers. In some

states each type has a distinct size and shape, in others all are of the same shape and size except the route marker which is generally distinctive. Guide signs serve to indicate the distance and direction to various points and are placed near cities and at the junction of important roads. Caution signs are placed at the approach to cross-roads, curves or other places where the driver should observe caution. Danger signs are placed at the approach to railroad crossings, turns, busy intersections, or other places of a similar nature. The difference between the caution sign and the danger sign is one of degree of danger only. Route markers are placed at frequent intervals along established routes and carry the route name and number and sometimes the mileage from the beginning of the route in the state or from some designated city.

These signs are best set on posts as near the traveled way as is safe and the post should carry no information except the official sign.

Foot Paths.—In many localities there is a goodly volume of pedestrian traffic on the public highways and in the absence of any other provision for their convenience they will use the surface provided for vehicular traffic. This is often objectionable because of the element of danger involved. A foot path should be provided at the outer edge of the shoulder to care for pedestrians and bicyclists, or it may be placed back of the ditch in level country. It may be of gravel, shale, or cinders and have a width of 3 ft.

Camp Sites and Comfort Stations.—Comparatively little attention is devoted by highway engineers to the provision of facilities for travelers who wish to camp along the roadside, since municipalities have generally arranged for tourist camps and have maintained them. The time will come when camp sites will be a part of the highway and will be so maintained. The requisites of a good camp site are: (*a*) a well-drained, reasonably level area for camping purposes, (*b*) plenty of shade, (*c*) sanitary conveniences, (*d*) good water, (*e*) bathing facilities, (*f*) accessibility to all sorts of supplies and services. If the site is in or near a region of natural beauty, that enhances its desirability.

In addition to comfort stations provided in connection with camp sites there should be additional ones at rather frequent intervals along heavily traveled routes. All of these facilities should be cared for by the patrolmen assigned to the adjacent section of highway.

Problems

1. Two important cities are 50 miles apart by highway. A survey of feasible relocations shows that the distance could be reduced to 42 miles by a series of relocations paralleling a railway line. The traffic between the two cities is an average of 800 automobiles and 50 commercial vehicles per day. The pavement proposed for the route will cost $26,000 per mile. What is the justifiable expenditure for the relocations?
2. It is desired to provide curves of 1,000-ft. radius at each 90-deg. angle in a road with right-of-way 66 ft. wide. It is found that the grading on the new location will cost $3 per foot of length and on the old location 75 cts. per foot. The road surfacing will cost $1.75 per foot. What is the allowable expenditure for right-of-way and incidental costs if the traffic is 500 automobiles per day?
3. A road that is paved with asphaltic concrete has several curves of 450-ft. radius and the paved surface has been built with a superelevation of 0.06 ft. per foot of width. For what speed are the curves safe when the road is clean and dry? For what speed are the curves comfortable? For what speed are the curves safe when the pavement is icy?
4. What width of road surface should be provided for a traffic of 700 vehicles (automobiles, busses, and trucks) per hour? 3,000 per hour? 8,000 per hour? Assume the above traffic to be approximately equally dense in each direction.
5. What length of vertical curve is required to afford a sight distance of 400 ft. at the summit of a +7 per cent grade and a −5 per cent?

CHAPTER VI

THE DESIGN OF STREETS

There are some problems of design that are solved in the same manner, whether the improvement is for a rural highway or a city street, while others involve special considerations because of the differences in use. The design of street improvements, like that of rural highways, must be predicated on three kinds of traffic: vehicular, hydraulic, and pedestrian—with pedestrian traffic much more of a factor in the cities than it is in the country.

The pavement on a city street serves two functions: it carries vehicular traffic and conducts drainage water from the street area and from the adjacent property to an inlet to the underdrainage system. The pedestrian traffic is, of course, carried by the sidewalks and cross-walks at intersections.

A few cross-sections, which indicate typical designs for various classes of streets, are shown in Fig. 19.

The typical cross-sections illustrate the normal pavement in which the cross-section is symmetrical except where warping is necessary to secure a neat connection at the intersections with the other streets. The pavement proper is flanked by curbs of equal height, on the two sides of the pavement. The longitudinal grades of the center line of the pavement, the gutter line, and the top of the curb are all of the same slope.

On many projects it is impossible to employ the normal cross-section throughout, and certain acceptable deviations from the normal cross-section have come into general use. It may be necessary to shift the crown line of the pavement away from the center line, vary the curb height from place to place, and to carry the gutter grades on a slope different from that of the crown line. The pavement surface is said to be warped when the gutter grade line and the grade line of the middle of the pavement do not lie in a plane. Warped surfaces are quite common in paving practice.

Certain fairly definite principles underlie and limit these departures from the normal if the design is well conceived and these will be pointed out in the discussion that follows.

The design of street improvements involves separate consideration of a group of related problems. The more important are:

1. Determination of width of pavement.
2. Establishment of street grades.

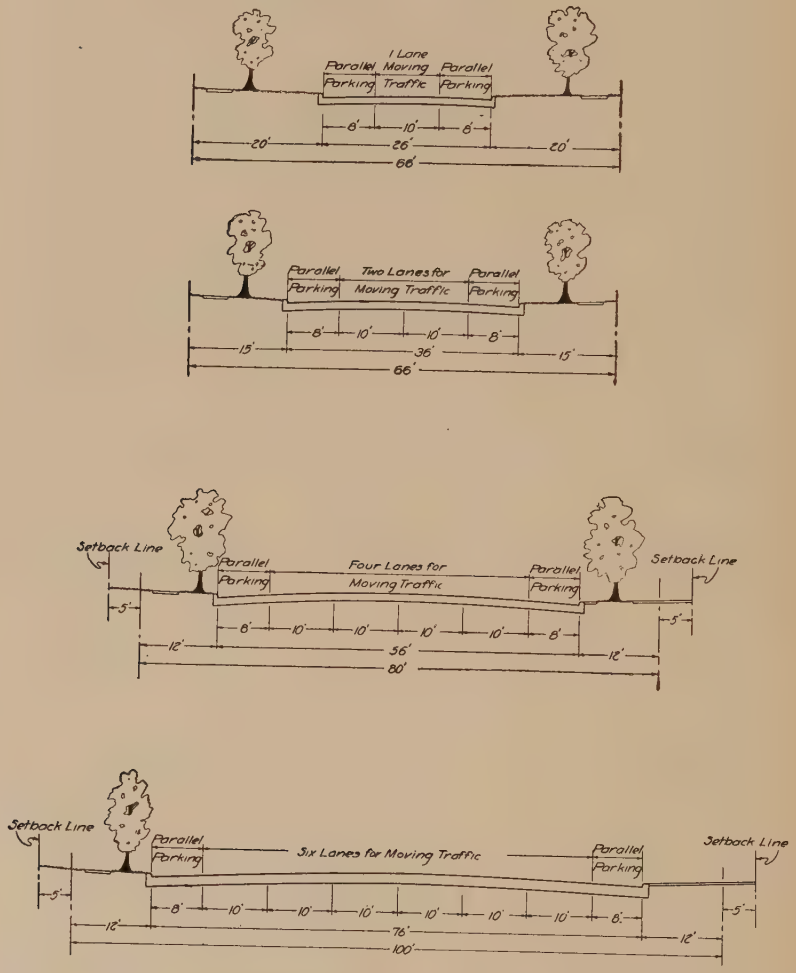


Fig. 19.—Types of cross-section suggested by Chicago Regional Planning Commission.

3. Design of crown for pavements.
4. Layout and design of intersections.
5. Design and location of drainage appurtenances.

6. Design of curbs or combined curb and gutter.
7. Design of sidewalks.
8. Design of pavement cross-sections (discussed in later chapters).

Since the design of a pavement cross-section is, in part at least, based on certain individual characteristics of the type, it will be more convenient to discuss that part of the problem of design in connection with the description of the type of pavement.

WIDTH OF PAVEMENT

The determination of the width of pavement for any location will be based upon the traffic capacity needed, the width of right-of-way, and the financial resources, important in the order in which they are listed. While traffic capacity is the first consideration, it is the most illusive factor with which the designer will deal. A method of estimating the traffic capacity of a rural highway was discussed in Chap. V, but it was pointed out that the method yielded only approximate results because of the difficulty of fixing average speed and headway. The same difficulties exist when dealing with estimates of the traffic capacity of the city pavements. In addition, the influence of cross-traffic, vehicles entering or leaving parking places, bus and truck traffic, pedestrian traffic at intersections, and traffic regulation systems all enter to complicate the problem.[1] Traffic counts have been entirely too few to permit generalizations and, because of the high cost of the municipal traffic census, there seems little probability that data on actual traffic capacities will accumulate very rapidly. Studies of traffic capacity that have been reported indicate that the maximum discharge per traffic lane, under good conditions of regulation and on arterial streets with good pavements, will rarely exceed 1,000 vehicles per hour, whereas the theoretical capacity is at least 2,500 vehicles per hour. It seems to be the rule that it is only in the event that important arterial streets are being developed that there is any systematic attempt to estimate the traffic capacity of proposed improvements.[2]

In certain cases, it is possible to estimate from the general character of a street the number of traffic lanes that will be required, which is the best that can be done unless definite data

[1] LEWIS, HAROLD M., "Metropolitan Traffic Control," *Roads and Streets*, Vol. 65, No. 5, May, 1926, p. 277.

[2] KELKER, R. F., JR., "Capacity of Roadways," *Roads and Streets*, Vol. 65, No. 1, July, 1926, p. 9.

on traffic are available. It will be convenient to consider the following typical kinds of streets.

1. Residential streets carrying little through traffic.
2. Residential streets carrying through traffic.
3. Streets in retail business areas.
4. Streets in wholesale and manufacturing districts.
5. Boulevards or arterial streets with traffic restrictions.
6. Arterial streets for mixed traffic.
7. Effect of car lines on required width.

Local Streets.—The simplest case is that of a local street which is intersected by through streets that permit traffic to move away from the district. These local streets may be built up with individual residences or with apartments and scattered small shops. The minimum width permissible is that which will provide three traffic lanes, two of which may be occupied at times by standing vehicles, leaving one clear lane for moving traffic. On the usual basis of 10 ft. as the proper width for a traffic lane, such a street would have a pavement 30 ft. wide. In outlying areas of low valuations and very light traffic, this might be reduced to 26 ft. If apartment houses and high-class individual residences predominate, the ordinary minimum width is four lanes, or 40 ft. This might be reduced to 36 ft. in exceptional, or intermediate, cases. The presence of standing traffic must be accepted as inevitable on such streets and room for moving traffic provided in addition to that required for standing or "parked" vehicles.

Through Streets in Residential Districts.—Streets of this type carry not only the traffic that serves the residences on the street and in the vicinity but also appreciable amounts of traffic having origin and destination outside the district—through traffic. The minimum width for such streets is 40 ft., or four lanes, which is the prevailing width of streets of this class. In some instances, the through traffic requires more than two lanes and yet the street width will not permit the construction of a 60-ft., or six-lane pavement and a compromise is reached by making the width 50 ft. This provides scant room for four lanes of moving traffic if the standing vehicles are placed parallel to the curb and close thereto.

Retail Business Streets.—Streets in retail business districts range all the way from the typical "main street" of the small city to those in the great department-store districts of the larger cities.

The problem of design in any district of this sort is to divide the available space between the vehicular traffic and the pedestrian traffic. The entire width of the street is utilized for sidewalks and pavement and there is no fixed rule for the division of the space that is universally applicable. It seems to require from one-third to one-half of the total street width for sidewalks and, in general, the higher proportion of sidewalk space is required in the districts devoted to the larger retail establishments. The minimum width of pavement is 40 ft. regardless of the size of the city, and in cities of a population of 15,000 or more the pavements should be wider than 40 ft. The retail- and department-store districts of the larger cities present a difficult problem in this respect, because curb lines have been long established and building lines can be moved back only at tremendous cost. Therefore, little change in pavement widths is to be expected in such districts, but minor changes are worked into the layout from time to time by way of correcting glaring inadequacies, either in pavement width or sidewalk space.

Warehouse and Wholesale District Streets.—Districts devoted to wholesale business and warehouses have need for all of the pavement area that can be provided and relatively little need for sidewalk space. On account of the space required by vans and trucks that are drawn to the curb to receive or discharge cargo, the standing traffic will require about 20 ft. along each curb. Two lanes for moving traffic will add 20 ft., making the total width of pavement 60 ft. This is the usual minimum. There are many variations of the problem of width in districts of this character. Sometimes the sidewalk is omitted entirely so as to secure enough pavement area for vehicular traffic. In other areas, the presence of factories necessitates some reasonable amount of sidewalk space. There are districts where the traffic cannot be accommodated if trucks are permitted to load and unload at the curb, so the business houses are required to provide space within the buildings for the standing traffic. Sometimes the alley is used for the purpose, but generally these do not provide enough room and must be supplemented by space inside the building line.

Street-car Tracks.—The actual traffic width required for a single-track car line is about 10 ft. and for a double-track line, 16 ft. The space occupied by the car tracks is used by vehicular traffic and no estimate of the extent to which the traffic capacity

of the street is reduced because of the street-car traffic is of any particular value. As a minimum, the pavement should be wide enough to provide for one lane of moving traffic and one of standing traffic on each side of the area used for street-car movement.

LONGITUDINAL GRADES

The term "grade" is used herein as meaning the slope in the longitudinal direction of the pavement, as along the gutter or center line. Grade is usually expressed in per cent, which is the change in elevation in feet in 100 ft. of horizontal distance. The term "elevation" is used to indicate the heights above datum of the various parts of the pavement. The terms "elevation" and "grade" are often used synonymously in engineering practice; hence the above definitions.

A grade line is a line (usually on a drawing) connecting the elevations of points on the pavement, curbs, or walk that are selected as control points for design or construction. There may be a grade line for the center line of the pavement, for the gutter, or for the top of the curb.

The principles outlined in Chap. IV apply to grades on streets as well as on rural highways, except that traffic conditions generally preclude taking advantage of momentum grades on city streets. The theory of grades is of service in fixing maximum grades but even in this respect topographical limitations often govern, rather than traffic convenience.

Maximum and Ruling Grades.—Since the designer is interested only in grades for improved streets, the maximum grade for an automobile street should be that which will permit automobiles to ascend at constant speed without shifting gears, and with the mixture of models of automobiles in use in 1928 this is about a 7 per cent grade. If commercial vehicles must be taken into account the grade should not exceed 4.5 per cent. Keeping in mind that descending vehicles must use the brakes on grades of more than about 4 per cent, it follows that the ruling grade should be as near 4 per cent as can be secured, with 7 per cent the limit. Topographical considerations will generally determine the actual maximum grade to be used.

The type of surface to be used must be considered in determining the limiting grades, or if topographical conditions preclude grade adjustments, the streets must be paved with a material suitable to the grade. If it is necessary or desirable to use a

certain type of pavement, such as creosoted wood block, then the grades must not exceed that which experience has shown to be the maximum permissible for that type.

Table IX gives safe limits of grade for the various types of surface if they carry mixed traffic, but as may be expected, there is little uniformity in practice in this respect.

TABLE IX.—ORDINARY MAXIMUM GRADES FOR VARIOUS TYPES OF SURFACE

	PER CENT
Wood block	3
Asphalt block	6
Brick	10
Sheet asphalt	5
Bituminous macadam	8
Bituminous macadam without seal coat	10
Concrete	8
Hillside brick	12
Granite block open joint (sand or pitch filler)	12
Bitulithic, asphaltic concrete	7

Minimum Grades.—The minimum grade is determined by hydraulic traffic rather than vehicular. The gutter along the pavement carries drainage water to the inlets to the sewers, and the minimum grade is that which will be sufficient to carry the water without accumulations. This is about 0.3 per cent grade for concrete or other smooth gutters, and 0.4 per cent for cobble or other rough gutters.

The grade of the crown line of the pavement is sometimes different from that of the gutter or the top of the curb. This scheme is often employed for streets in areas that are naturally about level and requires that the cross-section of the pavement change gradually from one of minimum cross-slope at the crests in the gutter grade to one of maximum cross-slope at the storm-water inlets. The exigencies of fitting pavement grades to existing sidewalks or drainage systems also requires that in some cases the gutter grade be at a different rate than the crown-line grade.

Hence it follows that the curb grade and the crown-line grade may each be 0.0 per cent and the gutter grade be the minimum of 0.3 per cent.

Curb Elevations.—The gutters along the pavement are the primary drainage channels for the water flowing off the adjacent properties, and the first principle of fixing curb elevations is

to insure that such water can flow over the curbs. The ideal arrangement would be to provide a slope upward from curb to sidewalk of not less than 2 per cent nor more than 3 per cent, and a like slope from the sidewalk to the building line. Good practice adheres rather closely to this ideal for the space between the curb and sidewalk, but the slope of the lawn is a matter for the individual owner and no common practice can be said to exist. Sidewalks are generally constructed before a street is paved and the lawns of residential property and the thresholds to the entrances to business property are adjusted to the sidewalks. When sidewalks have been constructed to a carefully established system of grades, it is comparatively easy to fix curb elevations, since the top of the curb must be at an elevation determined by the slope rule already mentioned. It frequently happens that sidewalks have been constructed without regard to a system of grades, and curb elevations will then be established so as to permit storm water to flow to the pavement throughout the length of the street, although some sections of low walk may have to be disregarded. Likewise, some building lots may be so low that it is impossible to fix curb grades so as to drain these lots, and the owner must fill them up before they can be drained. If sidewalks have been constructed on a street, the curb elevations should never be fixed until the adjacent walk grades have been considered.

The second principle to be observed in establishing curb elevations is to preserve the minimum grade requirements for the gutter, which in the normal case means that the curb grade should not be less than 0.3 per cent. If that cannot be accomplished because of the natural topography, then the gutter grades will of necessity be run independently of the curb grades.

The third principle to be considered in establishing curb grades has to do with the appearance of the completed improvement. It is that abrupt changes in curb grades should not be employed, and if straight-line grades are not practicable, then regular vertical curves should be employed. When straight-line grades are used, changes in rate of grade are less noticeable if they are made at street or alley intersections, where the continuity of the curb is broken. If the curb grade is made in the form of a vertical curve, the parabolic form is usually employed and its length is based on securing safe sight distance and fitting the existing topography as closely as possible. Where the parabolic form is

used, the necessary length is first determined and the elevations of the P. V. C. and P. V. T. ascertained. The elevation of the curve at the middle ordinate is then calculated from the properties of the parabola as follows:

$$E_3 = E - \tfrac{1}{2}[E - \tfrac{1}{2}(E_1 + E_2)]. \qquad (32)$$

Where

E_3 = elevation at middle ordinate
E = elevation at P. I. of the straight line grades to be connected by the parabola.
E_1 = P. V. T., elevation at point of vertical tangency.
E_2 = P. V. C., elevation at point of vertical curvature.

Elevations of intermediate points are readily calculated from the mathematical properties of the parabola.

Relation of Pavement to Curbs.—The general grade of the pavement is fixed by the curb elevations, since the pavement elevations bear a definite relation to the curb elevations. Some leeway exists whereby the pavement elevations may be established independently of the curb elevations, but no major departure is permissible. It is best to think of the pavement and curbs as an entity and assume that whatever circumstance affects the grade for one also affects the grade for the other. In special cases, the height of curb may be varied somewhat, or the curb may disappear altogether for short distances, particularly near intersections, but it is better to carry pavement and curb elevations so as to produce the normal cross-section so far as possible.

Unsymmetrical Cross-sections.—When the property on one side of a street is higher than on the other, the curb on the higher side of the street will be set at a higher elevation than the curb on the low side, to give a good appearance to the street and to minimize grading. This plan also serves to simplify the design of intersections on the street. The maximum permissible difference in the elevations of curbs in such cases is equal to the total crown for a pavement of double the width of the pavement in question. If the difference in curb elevations is less than the maximum that is allowable, the cross-section is designed as follows (See Fig. 20):

1. Determine the width of pavement for which the difference in curb elevation would be the correct total crown and divide by two, and designate this as W_1.

2 Let W designate the total width of the pavement, then $W - W_1 = W_2$, the width of pavement that will be constructed with the normal and the correct crown for a pavement of width of $2W_2$ is determined from one of the crown diagrams.

3. The crown line will be at a distance W_2 from the higher curb or a distance of $W_1 + \frac{W_2}{2}$ from the lower curb, and thus the elevation of the crown line and its position are fully determined.

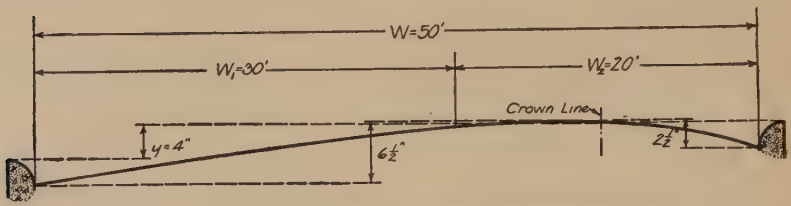


FIG. 20.—Illustrating design of unsymmetrical cross sections.

CROWN

When a pavement is constructed with a normal cross section, the surface is convex in form so that storm water will flow to the gutters.

No very rigid rules can be laid down to govern the amount of crown to use and there is not close agreement among engineers with respect to the amount of crown and the form of the transverse section.

Purpose of Crown.—Pavements are constructed with crown for drainage purposes, and therefore the amount and form of crown are determined by drainage requirements. If the rate of longitudinal slope is small the cross slope must provide the drainage. The amount of cross slope is therefore made sufficient to cause the storm water to pass quickly to the gutter. The smooth and impervious types require less crown than those types that may be somewhat absorbent or tend to become slightly uneven as they are used. The differences are so slight among the high-type pavements that it seems scarcely worth while to vary the crown with the type. If the longitudinal grades exceed 2 per cent, the cross slope may be reduced somewhat from the rate used on pavements on flat grades.

In some climates the drainage requirements do not necessitate more than a semblance of crown, but the pavements look better if they are crowned a little and also they will be easier to clean by flushing than if built without crown.

Form of Crown.—It has long been the custom to use the parabolic form of crown for pavements and in general it is satisfactory, except that for wide pavements, for example those 60 ft. or more in width, the parabolic form has been criticized because the central portion will be nearly flat. On a 50-ft. street with a total crown of 6 in., the total crown of the central 25 ft. would be 1.5 in. if the parabolic form is used. Some designers feel that to be too little and prefer to use a form of curve that gives a little more cross slope to the central part of the pavement.[1]

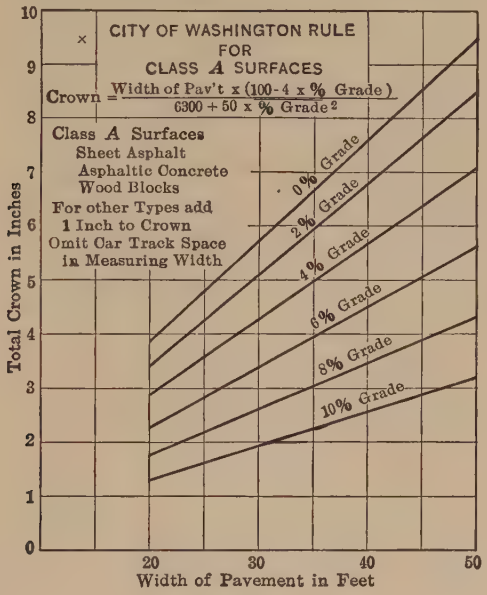


FIG. 21.

Amount of Crown.—There are in use a number of rules for determining the total crown to use for streets of various widths and grades. These are empirical in character but have had wide use and have proven acceptable. This is especially true of the Rosewater rule, developed first for use in Omaha, Neb. The author has used a simple rule which seems to have been quite satisfactory but provides for somewhat less crown than some of

[1] BESSON, F. S., "Methods for Determining Street Pavement Crowns," *Eng. News-Rec.*, Vol. 90, No. 14, Apr. 5, 1923, p. 627.

ROSS, ERNEST S., "Designing Pavement Crown," *Eng. News-Rec.*, Vol. 99, No. 4, July 28, 1927, p. 152.

the others, which is believed to be advantageous for motor traffic where the problem of skidding must be considered. In Figs. 21 to 23 are several diagrams for determining crown in accordance with the practice in certain cities which have standardized on certain rules that have been applied with acceptable results.

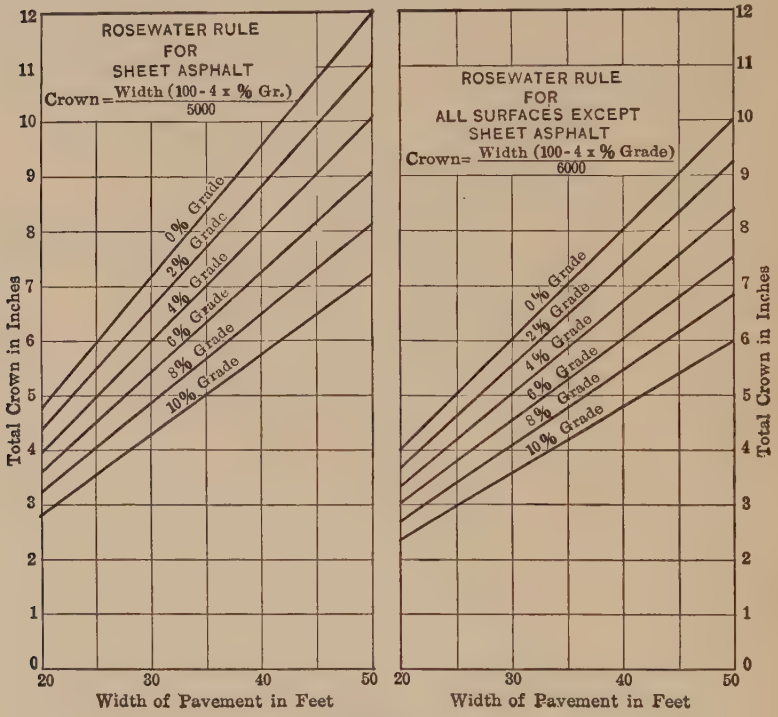


FIG. 22.

INTERSECTIONS

The design of the intersection of two streets has considerable influence upon the grade line of each of the streets between intersections, particularly when the rate of grade on the streets is such as to require flattening of grades across intersections. The design of intersections involves determining the type of treatment in general and the establishment of the exact elevations of the curbs and pavement at control points in the intersection and adjacent thereto.

Types of Intersection.—Intersections are of two general types but the two are not so very clearly defined in practice and it is

not uncommon to see intersections where one or two corners are of one type and the remainder of the corners are of the other. It is convenient to discuss the two as distinct types, which for convenience, are designated *A* and *B*, even though many variations from type may be expected.

Type A.—This type is designed with normal curb exposure through the intersection. At each pedestrian crossing there will be a step equal to the curb height and a small flow of water near the curb during periods of pre-

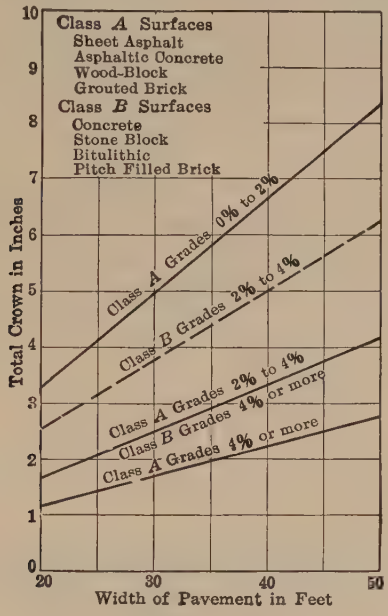


FIG. 23.

cipitation. This design is used in districts where the space between the curb and the building line is entirely occupied by sidewalks and in other districts where vehicular traffic is heavy and pedestrian traffic is also fairly heavy. It is intended to keep the vehicular traffic strictly to its own area thus protecting pedestrian traffic. An intersection of this kind is shown in Fig. 24.

Type B.—Another type of intersection is designed with the pedestrian crossing raised to the elevation of the top of the curb. It is intended to eliminate the step at the curb and, in a measure, to afford a dry crossing for pedestrians in wet weather. It is a type that is extensively used in residential districts and in the less congested business sections of the cities. In some cities it is used throughout the city on the projects of recent design. There are many differences in the details of the designs of intersections of this type, but all seek to accomplish the same thing. One development of an intersection of this kind is shown in Fig. 25.

Curb Radii at Intersection.—The radius of curvature of the curbs at intersections is made as great as is possible without encroaching on sidewalk space. In residential districts where

FIG. 24.—Showing conventional intersection design for a business street.

there is a width of turf or an unused space between the curb and the outer edge of the walk, the curb radius is fixed at about 20 ft. If a curve of 20 ft. radius, tangent to the street curbs, causes the

FIG. 25.—Showing intersection pavement warped up to the top of the curb at the cross-walk.

curved curb to fall within the walk intersection, a center of curvature may be selected that will bring the curved portion of the curb to the outer corner of the sidewalk intersection, but in

consequence not tangent to the street curbs. The alternative is to use a shorter radius of curvature that will bring the curved curb to the outer corner of the sidewalk intersection and at the same time keep it tangent to the street curb.

At alleys and private driveways, the radius is fixed at about 20 ft. with the center of curvature at the property edge of the walk, even though the curve thus described does not come tangent to the street line. But if the distance from the center of curvature thus selected to the curb is more than 20 ft., a new center of curvature is selected to bring the curved section of curb tangent to the street curb. A little consideration of the path of a vehicle in turning corners or turning into alleys will make clear why the curve radius is fixed in this manner. These various designs are illustrated in Fig. 26.

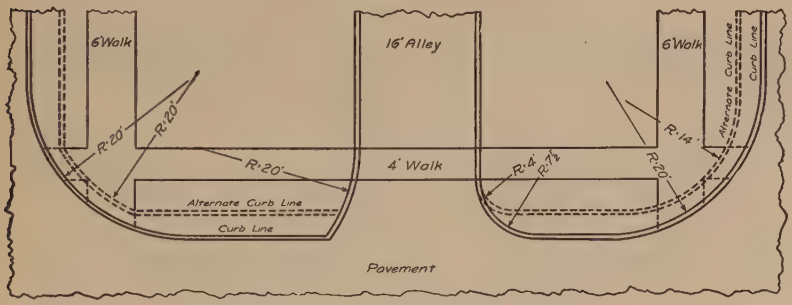


FIG. 26.—Illustrating designs of curb lines.

In districts where the entire area between the curb and the building line is occupied by sidewalks, a long-radius curb at the corner reduces the sidewalk area to an objectionable degree. Generally there is insufficient room on the sidewalk at best and the curb radius is fixed as a compromise between two conflicting requirements. The exact radius adopted varies between 6 and 10 ft.

Elevations at Intersections.—In establishing the elevations of walks, curbs, and pavements at street intersections, due consideration is given to safety for the vehicular traffic, the comfort and convenience of pedestrians, and the disposal of storm water.

The question of safety for vehicular traffic arises more especially at intersections of streets having relatively steep grades. Adverse cross-slope to the pavement within the intersection may create a hazard for vehicles that seek to turn the corner. In the

ideal intersection, which can be secured when approach grades are very light, the pavement within the intersection is either without noticeable cross-slope or else slopes downward toward each curb corner. One or the other of these conditions should be approached as nearly as possible.

The convenience of pedestrians will be served if there is no step at the curb or, if there must be one, it is of moderate height,

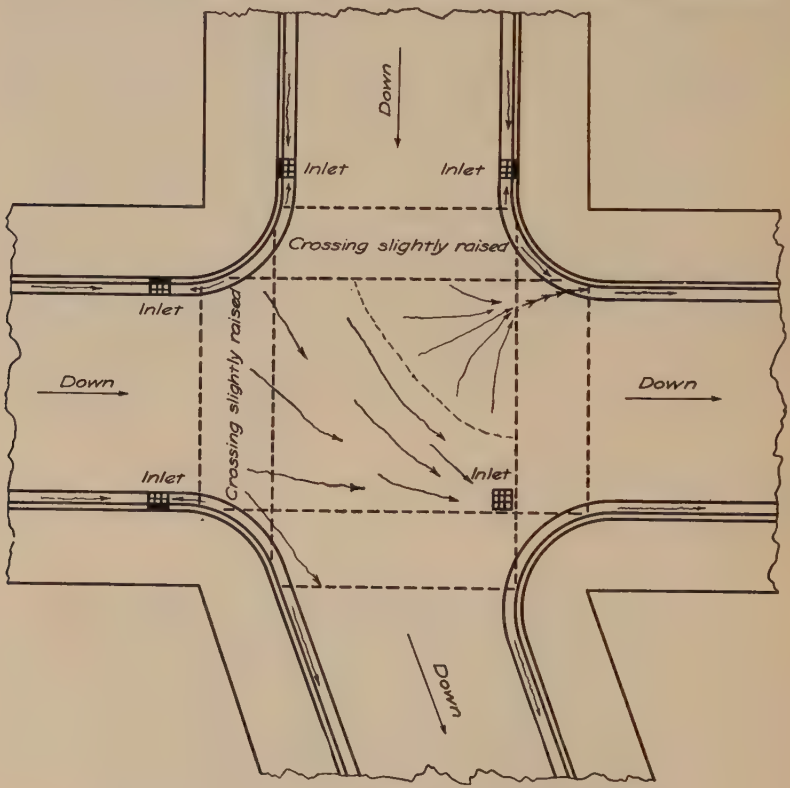


Fig. 27.—Illustrating drainage of intersection pavement.

say 0.5 to 0.6 ft. If the pavement is warped up to the top of the curb, the slope should be flat enough to preclude serious danger when the pavement is coated with snow or ice. The sidewalks should have a moderate cross slope, since high cross-slope is uncomfortable and dangerous. At the corner, the cross-slope should be held to a maximum of 6 per cent but wherever possible should be kept down to about 2 per cent. The longitudinal slope of the sidewalk must conform to the grade of the street.

Storm water should be disposed of in such a manner as to contribute to the comfort and convenience of pedestrians and vehicular traffic as is explained in another place.

The task of embodying all of these diverse requirements into the design of an intersection is by no means simple, and those engineering organizations that are confronted with the problem devote a great deal of time to the solution of each specific case. Unfortunately no very definite rules of procedure can be laid down because the conditions that arise are so diverse. A few general principles (and even these are by no means universally accepted) may be suggested by way of affording a beginning of the solution of any specific problem.

SURFACE DRAINAGE

In those portions of a city that are fully paved the storm water from the paved area, the sidewalks, and all or part of that from the buildings and lawns, reaches the storm sewers after traveling some distance on the pavements, and gutters that flank them. Where the area is built up with business buildings, the roof water may be carried to the street gutters by concealed pipes or be carried directly to the storm-sewer system. But in such districts the entire street is generally covered with the pavements and the sidewalks and all of the run-off from this area follows the pavement gutters to the inlets to the storm sewers.

It sometimes becomes necessary to pave certain streets in the smaller cities or in the suburban districts of the larger ones before complete storm-sewer systems are provided. The disposal of storm water from the paved area becomes a troublesome problem in many projects of this character because it must be accomplished entirely by means of surface drains, with culverts under streets that cross the drainage lines. If surface water must be carried across a pavement, a depression, often referred to as a "valley gutter" because of its cross-section, is provided in the surface to accommodate and concentrate the flow. But a gutter of this type is very objectionable from the traffic standpoint unless it is carefully designed with a view to its riding qualities. These cross gutters should be avoided so far as possible, but sometimes they are the only means to the end. In general, streets should not be paved until after storm sewers are installed.

Drainage Principles.—The following may be set down as the fundamental considerations of the surface-drainage system on paved streets:

1. The storm water should be disposed of in such a manner that pedestrians will not be compelled to cross streams of water that are of sufficient volume to be difficult to cross without wading. At congested crossings the form of cross gutter should not be in the form of an open trough or

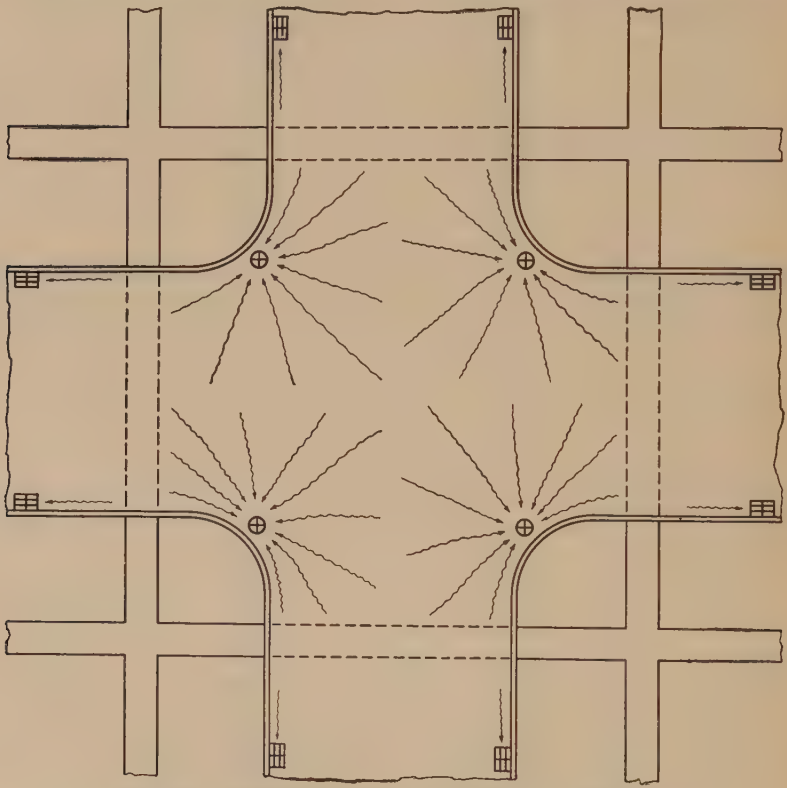


FIG. 28.—Illustrating drainage of intersection pavement.

otherwise create a hazard to pedestrians. The drainage from small areas may be carried across the cross-walks in shallow depressions, but the main drainage flow should be intercepted in such a manner that it does not flow over pedestrian crossings.

2. Storm water should be disposed of in such a manner that vehicular traffic is not compelled to cross streams of surface water near pedestrian crossings and preferably not at any place.

3. The device for directing and receiving storm water should not restrict the normal traffic area of the pavement, nor introduce objectionable unevenness in the pavement surface.

4. The drainage of the pavement should be accomplished in a manner that precludes the collection of objectionably large volumes of water in the gutters or on the pavement surface at intersections.

5. Central gutters are preferable in alleys because there are no curbs at the edge of the alley pavement.

6. On streets that must carry large volumes of water during periods of excessive rainfall, the entire paved area may be utilized for storm water to the exclusion of vehicular traffic. Where the outlet for such water is a flume in the prolongation of the pavement, the pavement cross-section may be concave instead of convex, to increase the capacity.

Pedestrian Crossings.—At each street intersection and sometimes between intersections, provision is made for pedestrians to cross the pavement, generally in the area formed by projecting the line of the edges of the sidewalks across the intersection. This space should be kept free from streams of flowing water, if possible. The drainage water from the walk itself will of necessity be flowing during rain storms but most of the flow from adjacent areas can be disposed of without its crossing the crosswalks.

Storm water that is flowing toward the intersection can be intercepted before it reaches the pedestrian crossing by means of one or more inlets placed 10 ft., or more, away from the crossing. If the grades are not too steep, the storm water from the crossing itself can be made to flow to that inlet.

The storm water from the intersection area may be carried across the several pedestrian crossings in shallow depressions in the pavement without undue annoyance to pedestrians. If the intersection is of large area it may be drained to inlets near the curbs and be thus disposed of before reaching the pedestrian crossings, requiring four inlets in the intersection.

Various arrangements of intersection drains are shown in Figs. 27 and 28.

Cross-drains.—At street intersections it is sometimes necessary to carry the gutter water of one street across the other. This is sometimes accomplished by continuing the gutter across the intersecting street as an open valley gutter, as has been explained. This is not objectionable if the volume of vehicular traffic that must cross the gutter is very small. It is a highly undesirable feature on streets that carry considerable traffic, even though the valley gutter be carefully constructed with a view to minimizing the discomfort of vehicular traffic. The valley gutter may be eliminated by constructing an underdrain

connected at each end to an ordinary curb inlet as shown in Fig. 29. The storm water will enter at one inlet and flow out at the

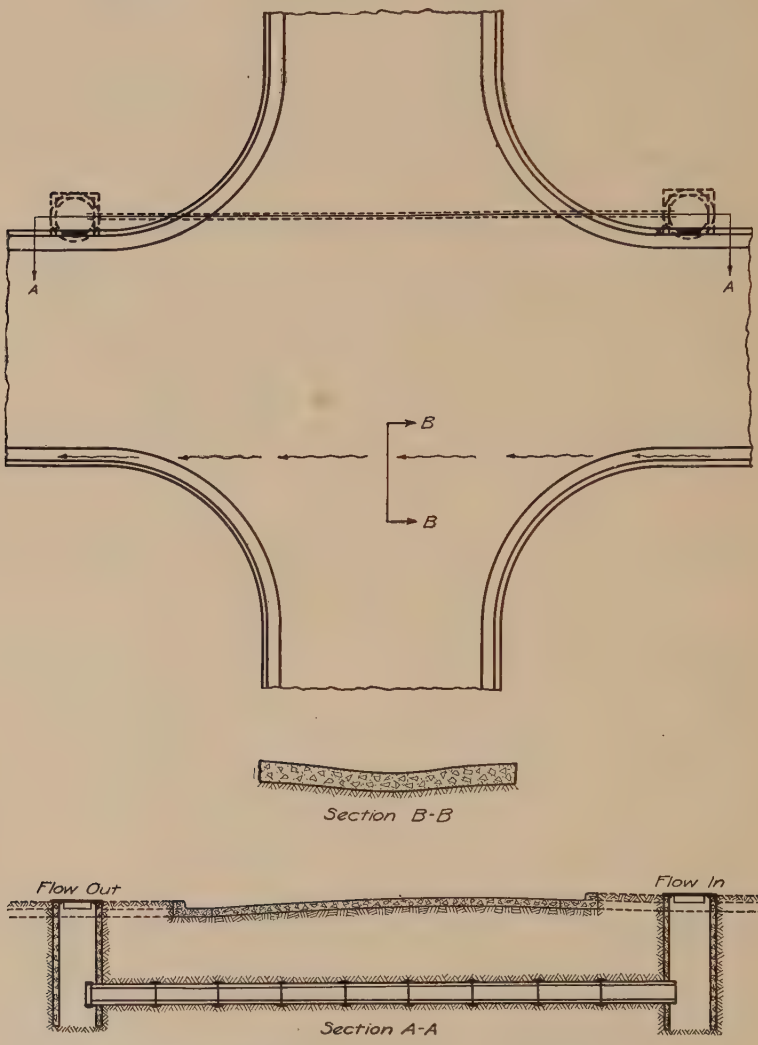


FIG. 29.—Illustrating cross drains for pavements.

other. That which remains in the inlets will gradually percolate into the soil, since the bottom of the inlet is not paved.[1]

[1] This type of drain, as constructed in Beloit, Wis., is described in *Concrete Highway Magazine*, Vol. 9, No. 11, Nov. 1925, p. 264.

STORM-WATER INLETS

It has been pointed out that the gutters along a pavement serve to carry storm water to the inlets to the under-drainage system. The inlets employed for this purpose are usually developed by a city to fit the ideas of the various designers who work on the problem. Many foundries market a line of castings for use as covers for inlets and manholes and of course these are

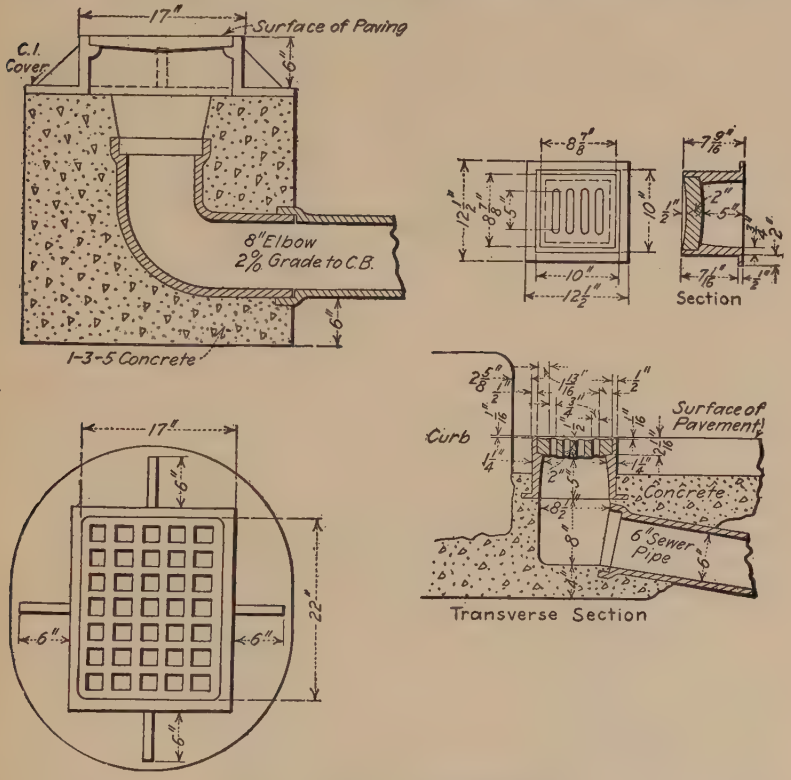


FIG. 30.—Typical curb inlet designs.

of a great variety of sizes and shapes. It really seems that there is an opportunity to simplify practice in this field.

In principle, there are but three types of inlets: the curb type, the gutter type, and the combined curb and gutter type. In each type, provision is made for removing the inlet grating or the cover to the inlet to gain access to the pipe connecting to the sewer for the purpose of cleaning. In general, the inlet drain

pipe should lead to a manhole through which the storm sewer flows.

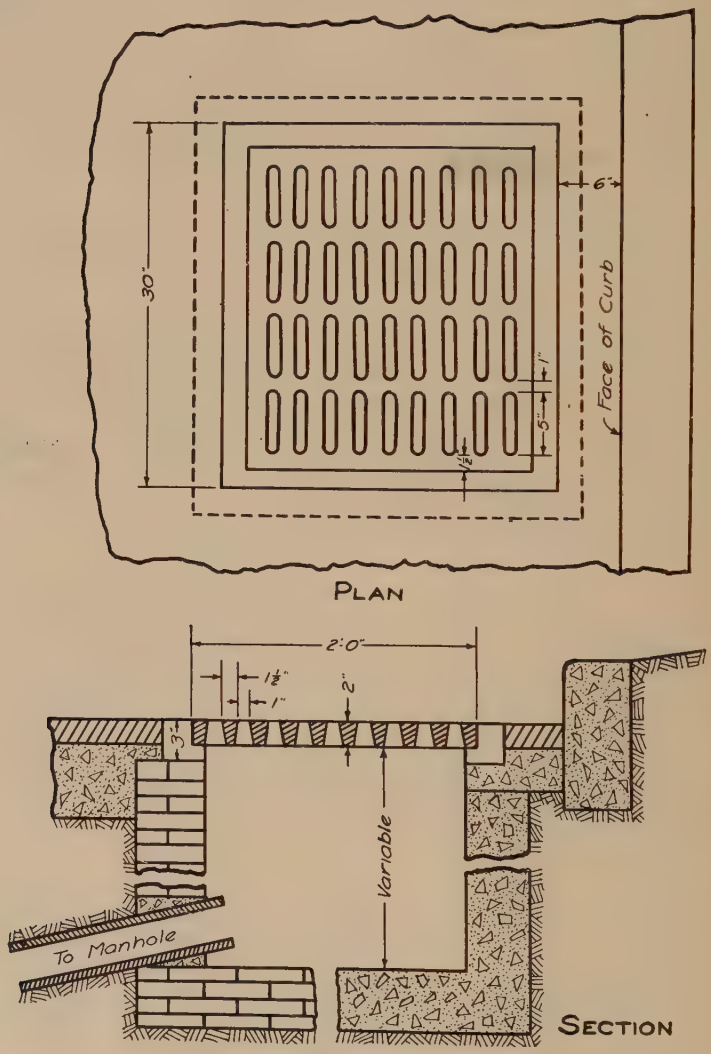


FIG. 31.—Typical gutter inlet.

Gutter Inlets.—Gutter inlets consist of a heavy iron grating supported by an iron frame, the whole assembly resting on a special vault or receptacle from which a line of sewer pipe leads to a manhole. In some types, the receptacle consists of a casting

which is set in place and then surrounded with concrete. In other cases, the receptacle consists of a brick or concrete chamber which is just deep enough to permit installing the sewer pipe that leads to the manhole. The distinguishing characteristc of this type of inlet is that the grating is designed to be placed in the pavement in the gutter area and to fit the contour of the pavement so that traffic can pass over the inlet. The gutter inlet is easily obstructed by debris carried to it by storm water, and therefore this type is not generally used on streets where the storm water carries any quantity of leaves, grass, paper, or similar refuse. It is used in those districts in the cities where the streets are kept clean by patrols and there are no trees or lawns. Typical gutter inlets are shown in Figs. 30 and 31.

Curb Inlets.—The receptacle of a curb inlet is placed behind the curb and consists of a brick or concrete chamber to receive the storm water, which flows in through an opening in the curb. The sewer pipe leading to the manhole is built in near the bottom of the receptacle. The feature of this type of inlet is that water enters by horizontal flow through an opening in the curb and consequently the opening is almost completely self-cleaning. Excessive quantities of debris may build up an obstruction that will finally close the inlet opening, but this does not occur nearly as frequently as with the gutter type of inlet. The opening in the curb may be formed in the concrete or it may be formed by a casting that fits the curb cross-section and affords the required opening. The larger openings are usually framed in metal. The curb type of inlet is very generally used where large quantities of water must be handled. The opening in the curb may be made of any length necessary and the inlet receptacle of very large capacity. The opening through the curb should never be less than about 2 ft. long nor less than 4 in. high, and should not be fitted with a grating or vertical or horizontal bars, as these merely serve to catch floating rubbish which will clog the opening. In the older installations vertical bars were used to prevent draft animals from slipping a leg into the opening.

Curb inlets are suitable for any location where there is space behind the curb for the receptacle. It cannot be used in a city where the sidewalk fills the space between building line and pavement, and the space under the sidewalk is utilized for basement rooms. Typical curb inlets are shown in Figs. 32 and 33.

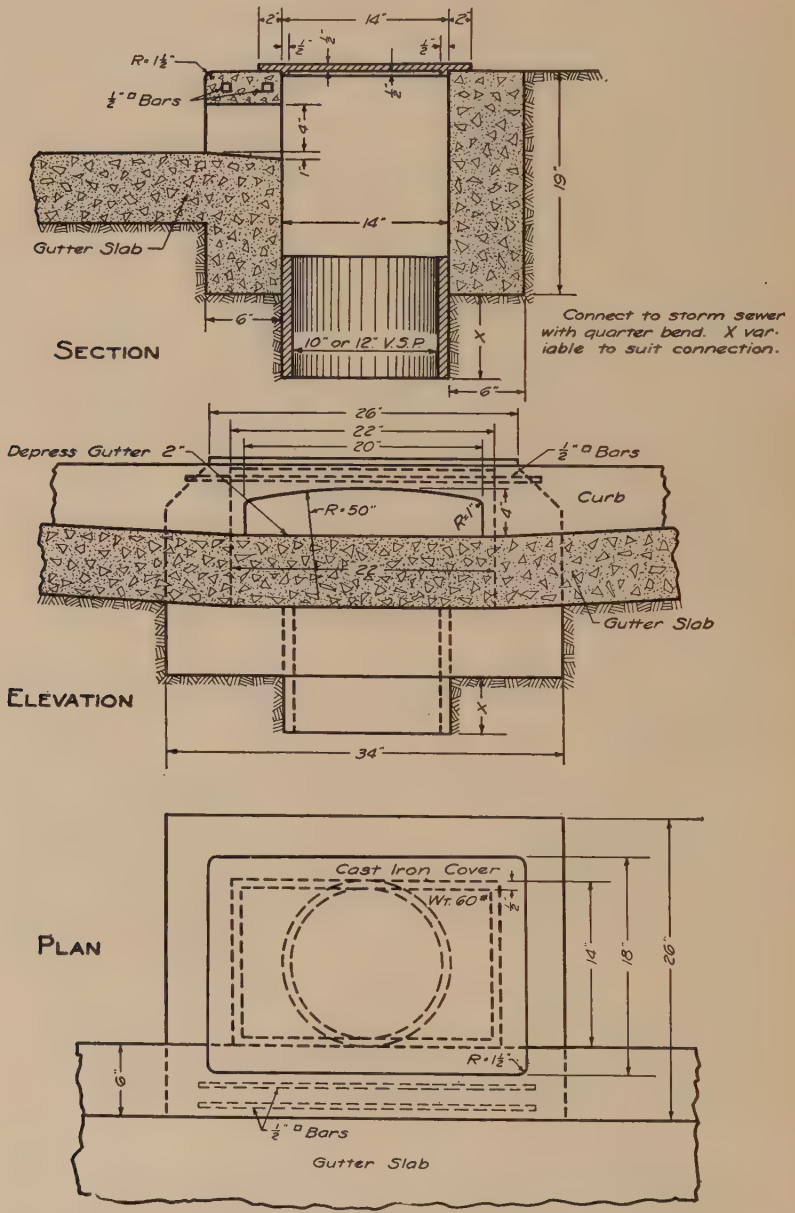


FIG. 32.—Typical curb inlet.

Combined Curb and Gutter Inlets.—As the name indicates, these are a combination of a gutter inlet with a curb inlet, with

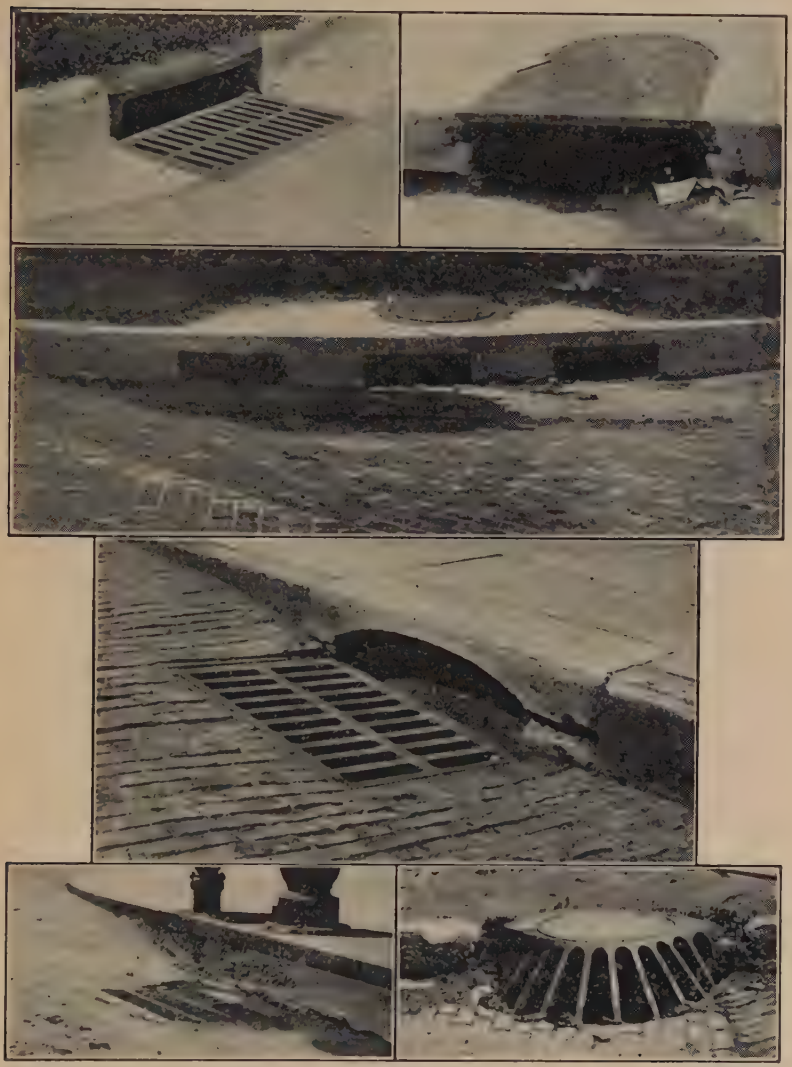


Fig. 33.—Types of inlets and castings.

a single receptacle underneath. They were at one time used quite generally with combined concrete curb and gutter but are gradually waning in popularity for the very good reason that

they cost more than the other types and are no better. Typical curb and gutter inlets are shown in Fig. 33.

Catch Basins.—A catch basin is like an inlet except that the receptacle is considerably deeper and the outlet tile connects at some distance above the bottom of the receptacle. It was expected that debris of various kinds would collect in the bottom of the catch basin and not flow to the storm sewer. Of course the catch basin had to be cleaned periodically or it would fill up until it functioned just as an inlet does. The catch basin is really a survival of the time when combined storm and sanitary sewers were used. The catch basin could be constructed with a water trap, or seal, so that odors from the sewer could not reach the street through the catch basin. Catch basins are no longer used to any very great extent on new construction but many of them exist on the older installations. Typical designs of catch basins are shown in Figs. 34 and 35, and a typical manhole design is shown in Fig. 36.

CURBS

Curbs at the margin of the pavement serve to define the edge of the traffic way, to hold in place the turf between pavement and sidewalk, to form one side of the drainage channel or gutter, and to trim and make sightly the whole street area. To a very minor degree the curb serves to retain the vehicular traffic to its allotted space but most self-propelled vehicles with rubber tires can readily cross any curb that would ordinarily be constructed along a pavement.

Curbs are of stone or of portland cement concrete, and the latter type is often constructed with a gutter slab integral therewith in the form known as the combined curb-and-gutter. Typical curb and curb-and-gutter designs are shown in Figs. 37 and 38.

Dimensions.—The maximum height of curb is fixed by appearance and economy as well as by the desire to make it possible for a pedestrian to step readily from the gutter onto the curb. The requirement is not very rigid but 0.6 ft. is generally considered to be the maximum height desirable, with 0.5 ft. the most common height. As might be expected, considerable latitude is allowed the designer with respect to curb height.

The thickness of the curb is generally about 6 in. except where heavy loads are likely to bump the curb, when the thickness is

generally 8 in., or more, and in these locations the granite curb is more likely to be used than any other type.

Foundations.—Stone curbs are generally set on concrete, which is carried up both the front and back faces of the curb to hold it securely to line and grade. Where drainage conditions are bad and the curb is likely to be shifted due to the freezing of the water in the soil under the concrete, a layer of porous material such as gravel, broken stone, cinders or broken slag is placed under the concrete foundation. Where very stable soils exist and the climate precludes there being any disturbance due to freezing, the curb is bedded on a layer of tamped gravel or cinders. It will readily be apparent that in order to set stone

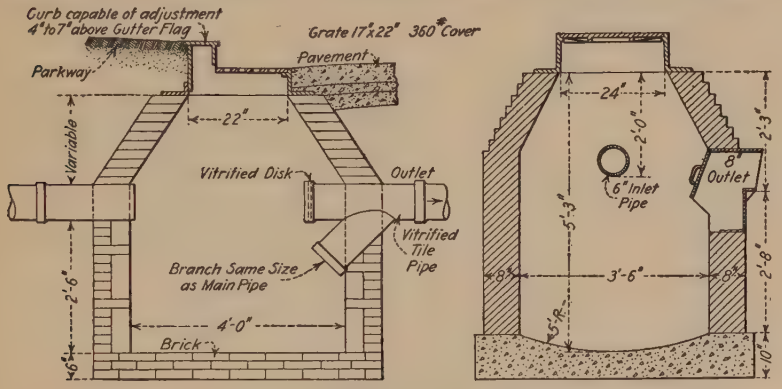


FIG. 34.—Catch basins without trap.

curbs accurately and permanently to grade some kind of stable bedding layer is necessary.

Concrete curbs are quite commonly placed directly on the natural soil, which is shaped and thoroughly tamped before concrete is placed. Curbs of this type can be constructed to line and grade. If bad drainage conditions exist, or the curb is likely to be disturbed by the freezing of the water in the soil under the curb, a bed of cinders, gravel, or other porous material is placed and tamped before the curb is constructed.

Combined concrete curb and gutter is placed on foundations exactly like those employed for concrete curbs.

Expansion and Contraction.—Curbs of all types and combined curb-and-gutter expand and contract from the effects of temperature and moisture, and unless adequate provision is made to compensate for this change in dimension, the curb will be

ruptured by the stresses induced. This rupture is quite likely to take place on curved sections where the curbs turn onto intersection streets or alleys.

Expansion of stone curb is provided for by leaving a space of about ⅛ in. between adjacent sections. Sometimes this space fills with inert material in the course of time and becomes inoperative as an expansion joint and it is a good plan to provide somewhat larger joints between the sections near curves.

Expansion of concrete curbs or curb-and-gutter is provided for by constructing them in sections about 6 ft. long with spaces of about ⅛ in. between the sections. As with stone curbs, it is advisable to provide additional space for expansion near curved

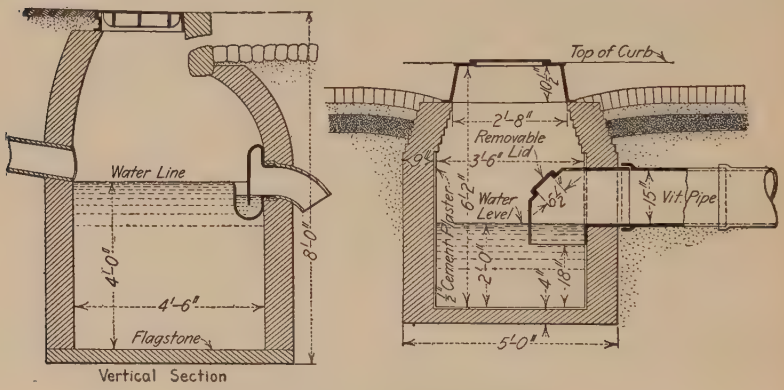


FIG. 35.—Catch basins with trap.

sections. This is sometimes done by leaving a space of about 1 in. between the last straight section and the first curved section of a line of curb or curb-and-gutter.

Curbing is often pushed out of line and sometimes actually ruptured by the thrust due to the expansion of sidewalks that abut the curb or that end at the curb. This sort of damage can be prevented by allowing ample expansion joints between curb and walk. In the case of sidewalks that end at a curb, as at intersections, a very wide expansion joint is necessary because sidewalks tend to increase in length with age. The expansion joints between adjacent slabs of the walk fill with inert material and cease to function as expansion joints; consequently, the expansion is carried the full length of the line of walk. But the walk is in short independent sections, and it does not decrease in total length when it contracts. In some cities the end of the

walk is built into a notch in the curb and may therefore expand indefinitely without disturbing the curb. Instances have been noted where the end of the walk had been thrust several inches beyond the face of the curb by expansion, but with the slot design no damage to the curb resulted. The damage that results from inadequate provisions for expansion is illustrated in Fig. 39.

Ornamental Gutters.—Sometimes it is desirable to add an ornamental feature to the gutter by way of giving a pleasing effect to the street design. This is done by using red vitrified

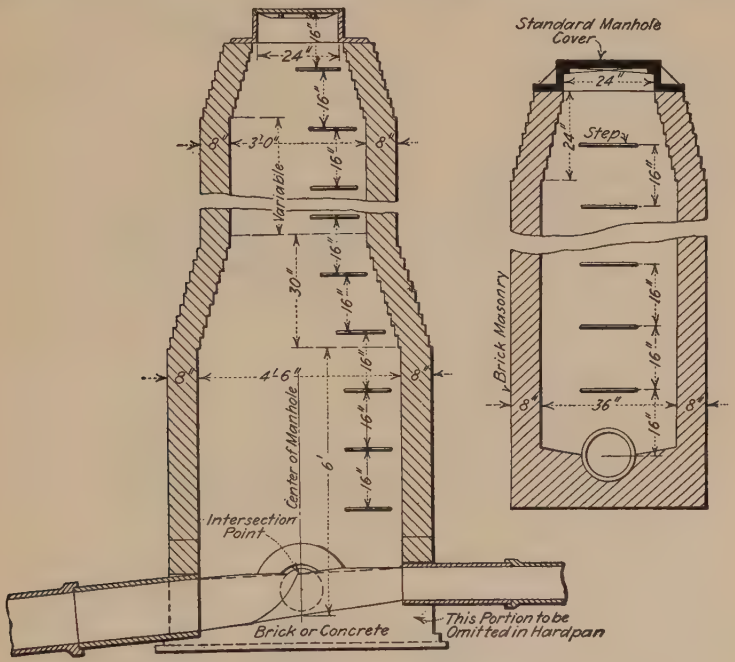


FIG. 36.—Typical manhole designs.

brick or cobble stones for the gutter slab. These are placed in various designs on a concrete gutter base. This design is particularly effective in combination with asphalt pavements.

In parks, estates, cemeteries, and in suburban districts cobblestone gutters are very effective and are often used. Generally the gutter is constructed without a curb and field stones of various sizes and colors are mixed indiscriminately in the gutter construction. These gutters are generally 2.5 to 3 ft. in width and about 6 in. deep. The stones are set in lean concrete or if the soil

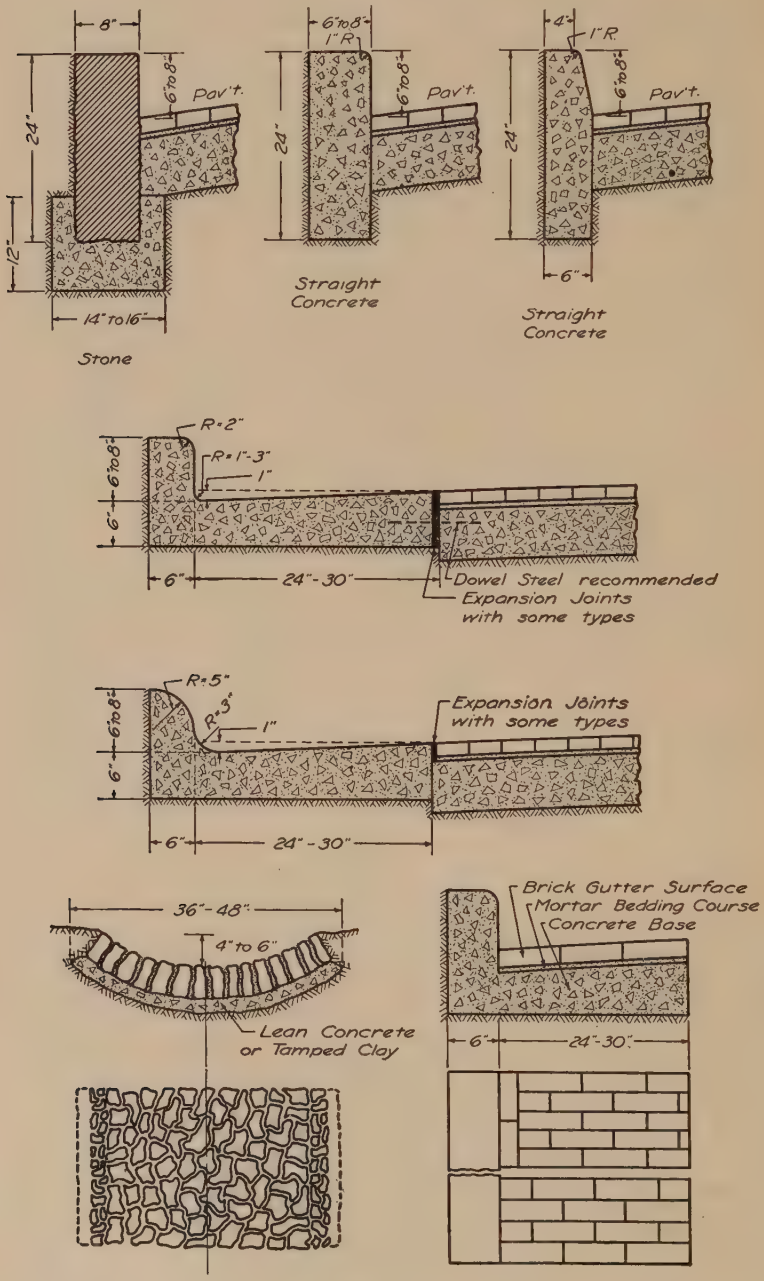

8"
6"to8"
Pav't.
24"
12"
14"to16"
Stone
6"to8"
1"R.
6"to8"
Pav't.
24"
Straight Concrete
4"
1"R.
6"to8"
Pav't.
24"
6"
Straight Concrete
R=2"
R=1'-3"
1"
6"to8"
6"
6"
24"-30"
Dowel Steel recommended
Expansion Joints with some types
R=5"
R=3"
1"
6"to8"
6"
Expansion Joints with some types
6"
24"-30"
36"-48"
4"to6"
Lean Concrete or Tamped Clay
Brick Gutter Surface
Mortar Bedding Course
Concrete Base
6"
24"-30"

Fig. 37.

is stable, on a carefully shaped and tamped soil foundation. Generally the spaces between the stones are filled with a lean concrete grout.

Concrete for Curbs.—For many years concrete curbs and curb-and-gutter were constructed of lean concrete with a fairly rich cement mortar facing about ½ in. thick on all exposed faces. The concrete for the body of the curb-and-gutter slab corresponded to a 1–3–6 mixture and the facing was 1–2 mortar. In recent years the trend has been toward the use of one mixture throughout, generally about equivalent to 1–2½–4 concrete. This provides sufficient mortar to insure good surfaces next to the forms. After the forms are removed the exposed surfaces may be rubbed with water and a wood float to remove lines left by joints in the forms. If metal forms are used it is rarely necessary to do any extensive dressing after the forms are removed. Curbs of this mixture are strong enough to resist all ordinary impact from vehicles.

Armored Curb.—Curbs adjacent to freight-receiving platforms and at other places where they are subject to abrasion from wheels of vehicles are sometimes constructed with a metal plate covering the upper 2 or 3 in. of the exposed face of the curb to reinforce it and protect it against abrasion. If the upper edge is rounded the protection plate is shaped to the radius of the edge.

SIDEWALKS

The design of sidewalks is fairly simple and reasonably well standardized, but the actual construction of sidewalks is too often sadly neglected. For general utility walks, which comprise the major proportion of those constructed each year, the portland cement concrete type is employed. Some other types are used where it is desired to secure ornamental effects.

Width of Walks.—Sidewalk widths are based on traffic requirements with 2 ft. the width of a pedestrian traffic lane. Pedestrian traffic counts and the analysis thereof are of some use in estimating the required width of sidewalk and have been used to a limited extent. In the main, little opportunity exists for exactness in this matter and walks are constructed of widths determined by judgment and experience.

In outlying residential districts the width is generally 4 or 5 ft.; in well-built-up residential districts 6 to 8 ft.; and in business districts 10 to 30 ft.

Cross Slope.—Sidewalks on streets are constructed to drain toward the gutter and consequently the slope is continuous

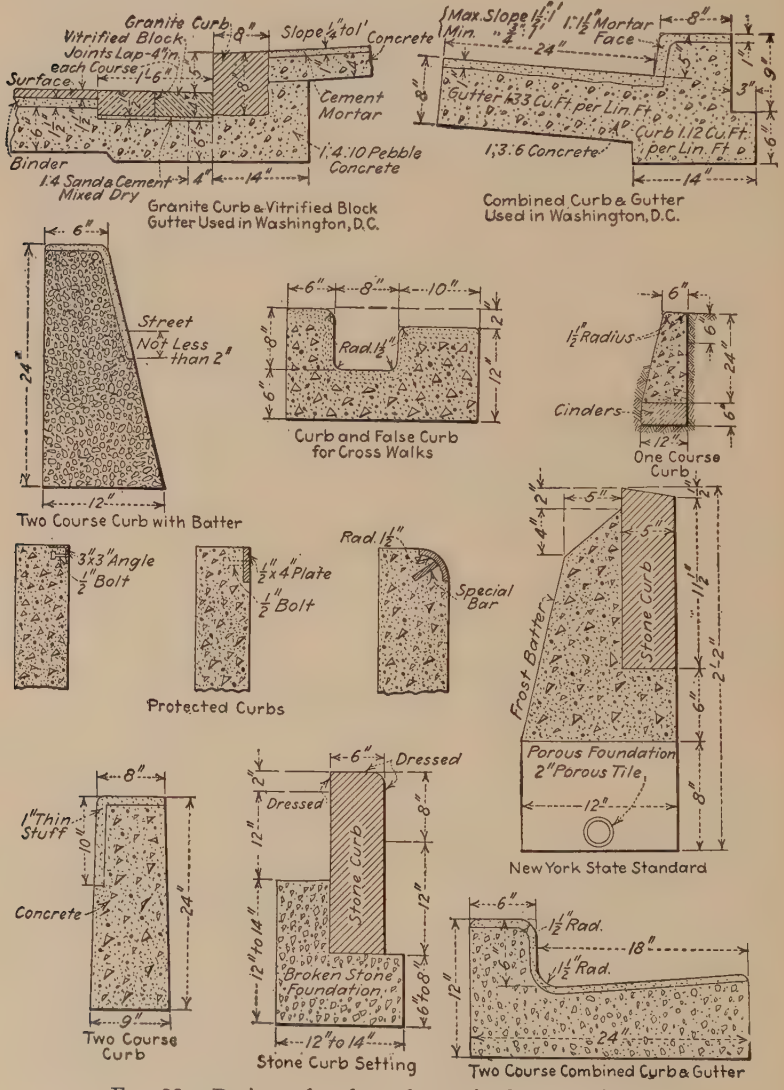


FIG. 38.—Designs of curbs and combined curb and gutter.

across the walk at the rate of about ¼ in. per foot of width. At intersections it sometimes becomes necessary to use a much

greater cross-slope for short distances but this is held to a maximum of 6 per cent if possible.

Walks in parks, private grounds, cemeteries, and similar locations may be constructed with cross-slope just as ordinary street walks, or they may be crowned slightly. If crowned the rate of crown is fixed at about ¼ in. per foot.

Two-course Concrete Walks.—This type of walk consists of about 4 in. of lean concrete (the equivalent of a 1-3-6- mixture

FIG. 39.—Illustrating need of expansion joints in curbs and walks.

of concrete with good aggregates) and ½ in. of wearing surface of 1–2 or 1–2½ mortar.

If drainage is poor the walk is provided with a ballast layer of porous material such as cinders or gravel. More often, the base course is placed directly on the natural soil.

The base course of rather dry concrete is placed and tamped and the wearing surface is then placed on the green base, struck off to the level of the forms and trowel-finished. To get a smooth, glazed appearance a steel trowel is used. To secure a granular

non-slippery surface a wooden float is used for finishing. Sometimes the surface of the green concrete is dusted with granite chips, carborundum or some similar sharp-grained substance, which is incorporated into the surface by floating or troweling, thereby reducing the tendency to slipperiness.

The walk is marked into sections about 4 ft. square with a grooving tool to create planes of weakness which will later develop

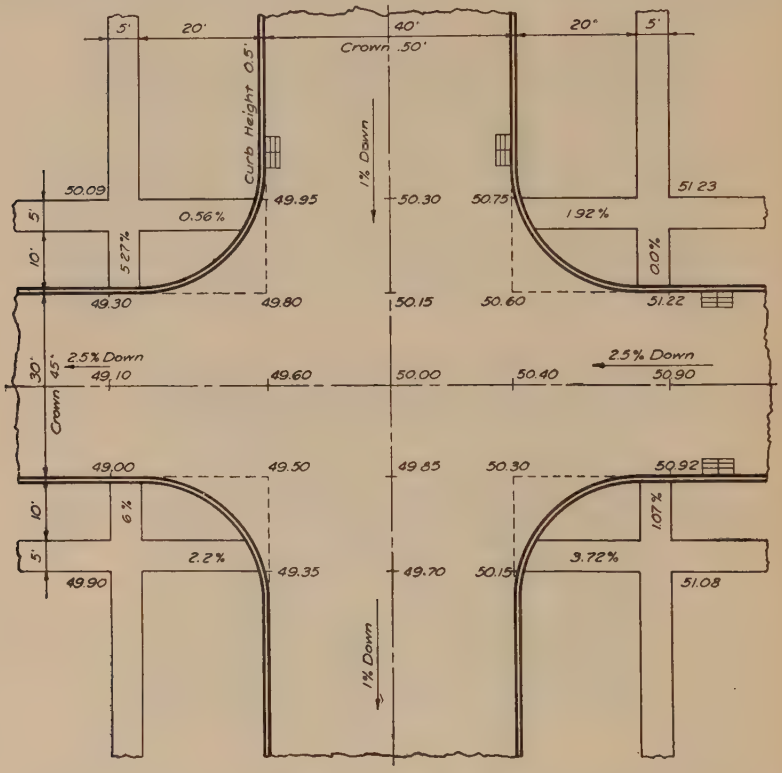


Fig. 40.—Intersection design for residential streets with light grades.

into cracks and minimize the formation of irregular cracks. Sometimes the walk is actually separated into sections by cutting the green concrete with a trowel and then finishing at the cut with a grooving tool.

One-course Concrete Walks.—Single-course concrete walks are composed of a single layer of concrete mixed in the proportions about equivalent to 1–2½–4 concrete of ordinary good

aggregates. Otherwise, these walks are constructed in the same manner as two-course walks.

Expansion and Contraction Joints.—Contraction joints form by rupture at the planes of weakness resulting from the grooving of the concrete walk as it is finished. Expansion joints, which are merely open joints about 1 in. wide, are provided near the intersection with other walks, and at the ends of the walk that

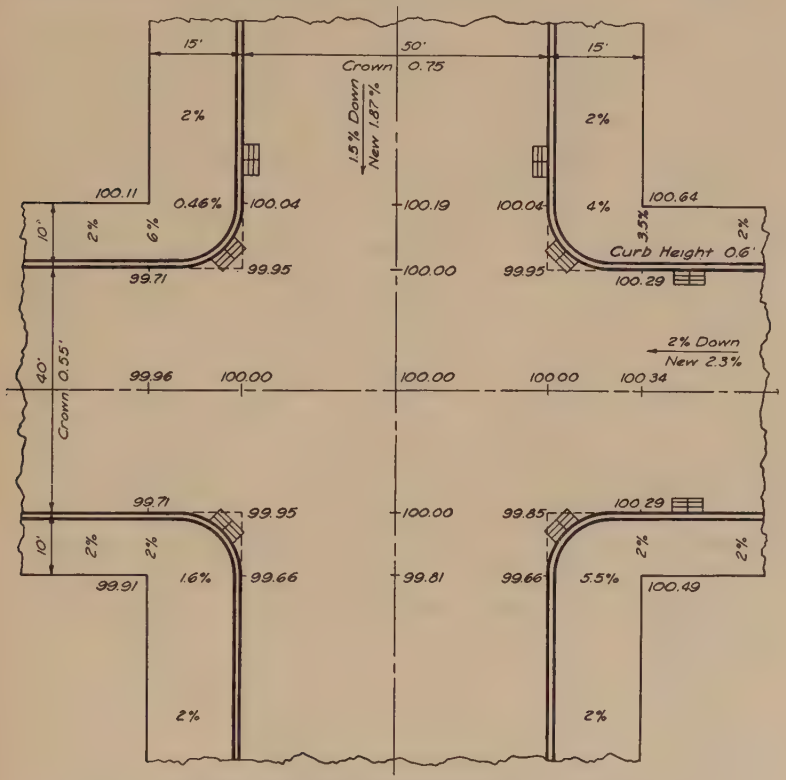


Fig. 41.—Intersection design for business streets with light grades.

abut curbs a joint 2 or 3 in. wide is provided. When the edge of the walk is adjacent to a curb, an expansion joint ½ to 1 in. wide, depending upon the width of the walk, is provided by inserting a sheet of expansion joint filler or by constructing an open joint which is later filled with bituminous material. These joints are filled because water flows across them and should be prevented from finding its way down behind the curb.

When walks are built over vaults or rooms, prism glass is installed and the walk consists of a concrete slab designed to carry a load. It must be kept water tight. Closely spaced expansion joints are provided which are caulked with oakum and then filled with a bituminous material.

ORNAMENTAL WALKS

In estates, parks, and similar places, it is sometimes desired to secure a walk that is more sightly than the ordinary portland-cement concrete walk. Several types of ornamental walks are used in such locations.

Tinted Concrete Walks.—By mixing lamp-black, red ocher, or other mineral colors in the concrete for the finish coat, the walk can be tinted as may be desired. Some very good effects are secured in this way. Some care must be exercised in selecting the sand to be used in such cases to make sure that the color in conjunction with the sand does not produce a blotchy surface, but any uniform sand, thoroughly washed, will be satisfactory.

Bituminous Walks.—If black is the color desired, it may be secured by applying a thin bituminous carpet to the concrete walk according to the method described for bituminous carpets on macadam in Chap. XVII, except that the dressing is generally rather fine sand and is used sparingly.

Bituminous walks of penetration macadam are also satisfactory if carefully constructed. The method is identical with that described for penetration macadam pavements in Chap. XVIII, but the total thickness is rarely more than 5 in. and the top course is about 1 in. thick.

Bituminous carpets are sometimes applied to gravel or macadam walks but are not very satisfactory.

Pebble Concrete Finish.—An effective finish to concrete walks is obtained by scattering pebbles, carefully screened to pass a $\frac{1}{2}$-in. screen and be retained on a $\frac{1}{8}$-in. screen, and of good colors, over the surface of the concrete as soon as it has been struck off to the correct level. The pebbles are then tamped or rolled until they are thoroughly bedded in the mortar. After the cement has begun to harden the surface is brushed vigorously with a stiff brush broom to expose the rounded pebbles.

A similar effect is secured by using for the surface course about 1 in. of concrete made of screened pebbles. The finish course

is spread and carefully tamped or rolled to the desired contour and then the mortar is brushed out to expose the pebbles.

Tile Walks.—Tile walks are constructed by laying tile of various colors and sizes in patterns on a concrete base. The base is of concrete of about 1–3–5 proportions and the bedding layer is of lean cement mortar.

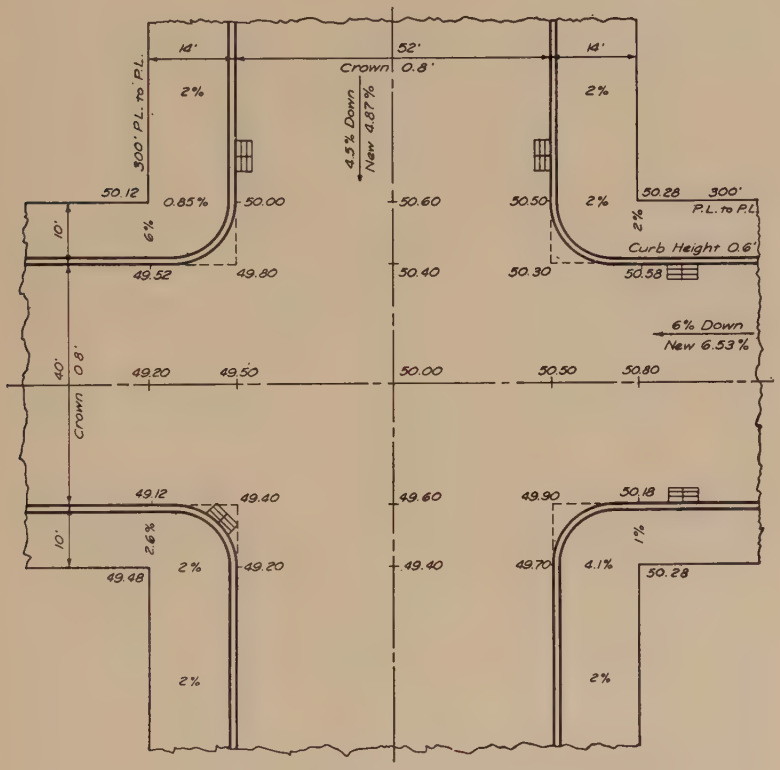


Fig. 42.—Intersection design for business streets with moderately heavy grades.

Gravel Walks.—These consist of a 5-in. layer of bonding gravel, screened to remove all pebbles larger than ½ in. in size. Such walks must be smoothed carefully at intervals for several months and may be expected to soften somewhat when there is any considerable amount of rain, but if care is exercised to secure gravel with low clay content this will not occur to an objectionable extent.

DESIGN OF STREET INTERSECTIONS

One of the most troublesome problems encountered in street design is the establishment of grades at intersections. So many and diverse are the conditions encountered that no simple rules can be laid down covering all cases. Moreover, practice has not been anywhere nearly standardized, nor can it be. The design of intersections is therefore a matter for special study every time it presents itself. A few fairly well-defined principles may be laid down that will serve as a basis for the work but the details will vary greatly among designs that are acceptable.

Streets with Grades Less than 2 Per Cent.—(*a*) The center-line grade is carried without a break across the intersection and the curbs on opposite sides of the street are not at the same elevation. The difference in elevation on a 40-ft. street with a 2 per cent grade will be 0.8 ft. and this can readily be taken care of by either varying the height of the curb so as to keep the gutters at nearly the same elevation, or by using an unsymmetrical cross-section for the street, or by both means. It may be desirable to keep the curbs and the pavement cross-section symmetrical on the more important of two intersecting streets, and have a break in the grade line of the other at the curb line of the first. This is frequently done where one street is a main thoroughfare and the other a cross street.

As a general rule difficulty is experienced in securing a safe and properly drained intersection if the difference in elevation of the opposite curbs is much greater than 1 ft., *i.e.*, on a 50-ft. pavement when the grade of the intersecting street is 2 per cent. When such is the case, method (*b*) may be used. Figure 40 shows the design of an intersection for a residence street with slight grades.

(*b*) The other method of designing intersections for streets of light grades is to make the elevations of the four curb corners the same. The grade lines of each street will then break at the curb lines of the intersection. This design is generally easily carried out on residence streets, but may be difficult in a business district on account of the established building-line elevations. From the standpoint of securing an intersection that is safe for vehicles it is to be commended. It has the disadvantage of putting the curb line somewhat below the level of the lots on the uphill side of the street, but this is a secondary consideration.

Figure 41 shows the design of an intersection for a business street with slight grades.

Streets with Grades over 2 Per Cent.—If streets are on grades greater than 2 per cent, and especially if they reach 5 per cent or more, it is generally impossible to carry the grades continuously across intersections because of the difference in height of urb that would result, although it might be done if the grades lie between 2 and 4 per cent. The grade cannot always be broken at the curb line because of the difficulty of securing reasonable grades to the sidewalks, especially on business streets. On

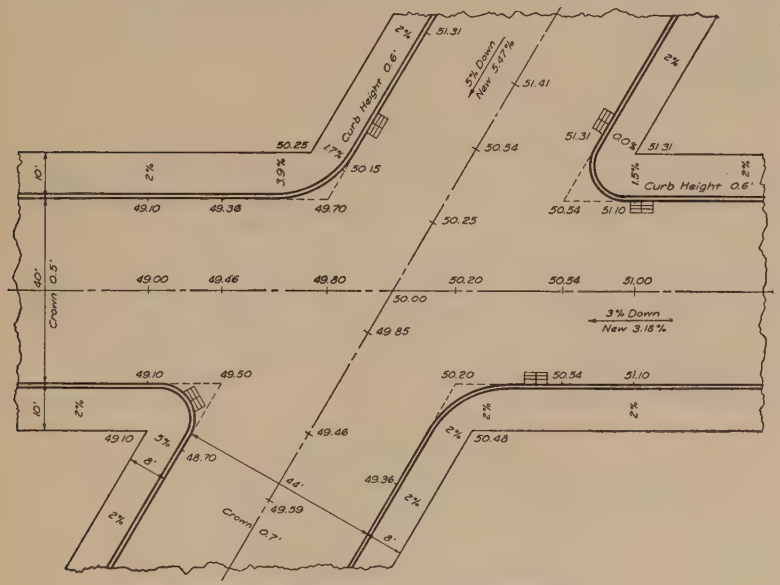


Fig. 43.—Design of a skew intersection.

residence streets it is sometimes possible to adjust the grades of walks if the street grades do not exceed about 4 per cent, and make the break in street grade at the curb line of the intersecting street. When that is possible it is the best solution of the problem as it usually increases the grades on the remainder of the block less than any other method of treatment. Figures 42 and 43 show designs of intersections for grades in excess of 2 per cent.

For business streets, satisfactory grades at the intersection are secured by flattening the street grade across the intersection,

making the break in the grade line at the property line of the intersecting street. It will easily be seen that this increases the grade along the remainder of the block.

This emphasizes the desirability of flattening the grade across the intersection only so much as is necessary to secure a satisfactory intersection. This can only be determined by repeated trial for any given intersection. On account of the variation of width of pavement and sidewalk no uniformity exists in the procedure, but whatever modification is made looks to one end, namely, to secure an intersection with reasonable slope and sidewalks that fit to the curb grade without undue cross-slope. This cross-slope of the walk may be as great as 6 per cent and in exceptional cases 10 per cent, but for ordinary cases should be held as low as 2 per cent.

For the intersection of streets crossing at excessive grades or for streets intersecting at acute angles, the problem becomes very complicated and the procedure outlined by Vernon S. Moon in a paper read before the Municipal Engineers of the City of New York has been widely quoted and commended. It is given as one of the examples of good practice at the end of this chapter. Besson has employed a system of contours for use in studying grades at street intersections and has used the method with good results especially on difficult intersection problems.[1]

CAR-TRACK PAVING

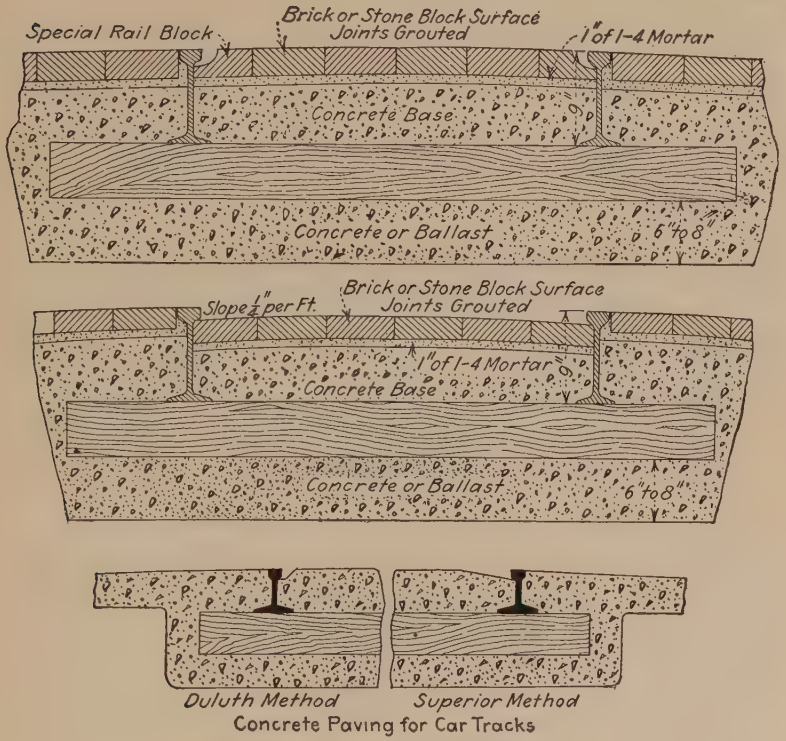
Whether car-track paving shall be of the same material as that used on the remainder of the street depends upon several conditions. Any street that carries a large amount of heavy truck traffic must have a very durable type of pavement and the car-track paving may be of the same type as the remainder of the street. Streets that are paved with stone blocks, wood blocks, or vitrified brick generally have car tracks paved with the same material.

If the traffic is mixed and is medium or light in volume the car-track paving may be of some more durable material than is used for the remainder of the street. At crossings where the tracks curve around corners or the trackwork is otherwise complicated the paving is likely to be cut up into small areas that receive severe service. In such cases it is good practice to pro-

[1] Besson, F. S., "Street Intersections Mapped Out by Means of Contours," *Eng. News-Record*, Vol. 90, No. 6, February, 1923, p. 255.

vide a very durable car-track pavement. Thus we often find that on streets with sheet pavements (sheet asphalt, asphaltic concrete, bitulithic, etc.) the car-track area is paved either with stone blocks or vitrified brick.

Even for moderate-traffic streets paved with sheet surfaces, it is common to use a "toothing" along each rail. even though



Concrete Paving for Car Tracks

FIG. 44.—Paving along T rails.

a sheet surface is laid between the rails. This toothing consists of one or two rows of stone blocks or vitrified brick laid along the rail with the long dimension parallel to the center line of the track.

Types of Car-Track Rails.—The type of rail appears to be an important factor in the life of the car-track paving. Three types, or modifications of them, are employed. If the rail is not adequately supported the continual vertical motion of the rail as the cars pass will gradually loosen the paving blocks adjacent to

the rail. Once loosened, water enters and softens the supporting soil under the ballast and hastens the deterioration of both track and pavement.

The effect of any movement of the track is increased if the paving blocks extend under the head of the rail.

T-rails.—The T-rail is of the form that is used for steam roads except that the rail is higher so as to permit the pavement being placed above the ties and to afford a more rigid support for cars. Where the rail is of this type a special shaped paving block is often employed to form a groove for the car-wheel flanges. This is not a satisfactory type of car-track paving for streets of heavy vehicular traffic because drivers will permit the wheels of vehicles to travel in the groove next the rail and the concentration of

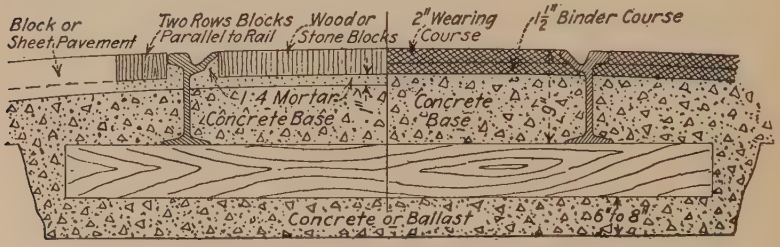


FIG. 45.—Paving along grooved rails.

traffic soon wears out the paving. Figure 44 shows the arrangement of the paving along rails of this kind. The T-rail is more economical for the street-car company as a rule.

Grooved Rails.—The shape of this rail is best shown by Fig. 45 which also shows the arrangement of the paving along tracks of this kind. Since the top of the rail is even with the pavement surface there is no tendency to guide the wheels of vehicles along the track.

Lipped Rails.—This rail is similar to the grooved rail as will be seen by reference to Fig. 46.

Track Construction.—Regardless of the type of rail used, increasing attention is being paid to the track construction and especially to the foundation. The thickness of the ballast under the ties varies with soil conditions but is rarely less than 6 in. and often is more than 1 ft. The difficulties encountered with car-track paving are generally due to insufficient stability of the track. Figures 44, 45, and 46 show the practice in car-track

construction on paved streets and represent the minimum requirements permissible if a stable track structure is to be obtained.

EXAMPLES OF GOOD PRACTICE[1]

1. Definition of Platforms.—The center-line intersection shall be deemed to be the point of intersection of the center lines except for cases where the center lines do not meet at a common point when it shall be the area included within the center lines at their intersection.

The curb-line platform shall be deemed to comprise the area included within the lines connecting the points on intersection of the curb tangents, or in the case of a street terminating at another

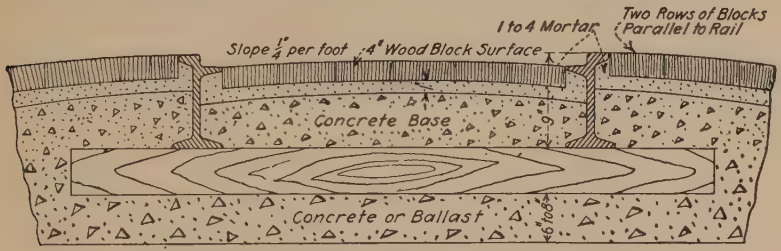


FIG. 46.—Paving along lipped or side-bearing rails.

street it shall comprise the area within the prolongations of the curb lines across the intersection and a line joining the curb tangents.

The building-line platform for rectangular intersections shall be deemed to include the area bounded by the prolongations of the building lines of both streets across the intersection so as to comprise the greatest platform area. In the case of other than right-angled intersections, it shall comprise the area bounded by the respective lines of each street and by lines at right angles or normal to the center lines and passing through acute-angled building-line corners, or the corners giving the greatest platform area. If the intersection of the center lines falls without the building-line platform, as above described, the said platform shall be increased sufficiently to include the said intersection. When the building-line corner is turned with a curve the platforms above defined shall be indicated upon the map unless herein definitely fixed.

[1] MOON, VERNON S., *Proc.* Municipal Engineers of the City of New York, 1911.

2. Definitions of Elevations Fixing Grades.—Unless otherwise indicated on the map, the elevation shown at a street intersection shall be deemed to be that fixed for the point of intersection of the center lines of both streets affected, or for the center line intersection.

3. Treatment of Center-line Intersection.—The center-line intersection, when it comprises an appreciable area and unless otherwise shown on the map, shall have a uniform elevation at its boundaries, and in determining the elevations for the other platforms herein described, the center-line intersection referred to as a basis of calculation shall be deemed to be the nearest point on the center line of each street at the boundary of the said platform.

4. Treatment of Platform for Streets Having a Light Grade.—If the grade of each of the intersecting streets is 3 per cent or less, as determined by calculating the rate between the established elevations, the elevation of the center lines of each street within the limits of the curb-line platform shall be the same as that fixed for the center-line intersection. The elevation of the curbs shall be determined as indicated in Paragraph 8. Provided, however, that the difference in the elevation of points on the center lines opposite any building-line corner, shall not provide a greater transverse sidewalk slope than that fixed as the maximum in Paragraph 7, in which latter event the building-line platform shall be used and the grades of that portion of the streets adjoining the said corners shall be flattened between the boundaries of the building-line platform and the center-line intersection, as provided in Paragraph 5(*a*).

5. Treatment of Platform for Streets Having a Steep Grade or Meeting at an Acute-angled Intersection.—(*a*) If the grade of any portion or portions of intersecting streets adjoining a building-line corner is over 3 per cent, as calculated between the established elevations, or if a further flattening of the platform grade is required to provide proper sidewalk slopes, for any part of an intersection described in Paragraph 4, the grades of the said portion or portions of each street shall be reduced between the boundaries of the building-line platform and the center-line intersection as follows: If the intersecting streets are of the same width, the grade of the street traversing the shorter block length adjoining the intersection shall be reduced one-third and that of the street traversing the longer block shall be reduced two-thirds. In case the streets have different widths, the grade of the wider

street shall be reduced one-third and that of the narrower street two-thirds between the above limits. All grades less than 3 per cent which are not herein required to be flattened shall be applied at the same rate as originally computed between established elevations. Provided, that in no case shall the maximum platform and sidewalk slopes fixed in Paragraphs 6 and 7 be exceeded.

Any excess in grade over that allowed in Paragraph 7 shall be removed by further flattening, as follows:

(*b*) Special flattening of platform grades for extreme cases of steep grades or acute-angled intersections. If the difference in elevation tentatively fixed for points on the center lines of intersecting streets opposite any building-line corner, after applying the minimum and up to the maximum transverse sidewalk slope on the higher and lower sides respectively, exceeds the maximum transverse sidewalk grades hereinbefore described, the elevation of each street at the boundary of the building-line platform shall be adjusted to remove the excess, the adjustment of each of the said elevations being directly proportional to the grade of each as originally flattened or applied.

For all cases covered by Paragraphs (*a*) and (*b*) the elevations at the intersections of the center line of each of the narrower streets or at the streets traversing the longer blocks, if they are of equal width, with the curb-line platform of the intersected street shall be the same as the elevation of a point on the center line of the intersected street immediately opposite the first-named intersection, except that the elevation at this point shall be abandoned when the grade along the center line between the curb-line platform and the building-line platform exceeds the grade as originally computed.

The grades of the center line of the wider street or of the street traversing the shorter block, if they are of equal width, shall be uniform between the exterior boundaries of the building-line platform and the center-line intersection, except that the maximum platform slope hereinafter fixed shall not be exceeded. The grades of the center line of the narrower street or of the street traversing the longer block, if they are of equal width, shall be uniform between the elevations fixed at the exterior boundaries of the curb-line platform, and also between the latter point and the center-line intersection.

6. Maximum Platform Grades.—The maximum allowable grade along the center line between the curb-line platform and

the center-line intersection shall be at the rate of 4 per cent, unless otherwise indicated on the map.

The grades along the center line between elevations established within the limits of a building-line platform shall be uniform, subject only to the flattening provided for in Paragraph 5 (*b*).

7. Transverse Sidewalk Grades.—Whenever practicable, the sidewalk shall slope upward in a direction at right angles to the curb toward the building line at the rate of 2 per cent.

The elevation of the sidewalk at the building-line corner shall be determined by applying this rate to the elevation of the curb giving the higher building-line elevation, at a point immediately opposite the corner, unless the resulting grade on the lower side exceeds 6 per cent, in which case the sidewalk shall be level on the higher side and a greater transverse sidewalk slope up to the maximum shall be used on the lower side.

The maximum transverse sidewalk slope shall be 6 per cent except in those cases where the street grade as originally computed on any street adjoining a building corner is more than 6 per cent, when the maximum slope shall be 10 per cent for either street, opposite the said corner. In no case shall the sidewalk at the building line be lower than that of a point immediately opposite it on the curb.

If the transverse sidewalk slope at the building-line corner is more or less than 2 per cent, it shall be made to agree with this latter rate at a point distant 25 ft. from the building-line corner.

8. Curb Elevations.—The relation between the elevation of the center lines and of the top of the curbs at points immediately opposite it at the boundary of and outwardly from the building-line platform shall be as follows: For roadway widths of 24 ft. or less the top of the curbs shall be 0.1 ft. higher than the center line. For roadway widths ranging from 24 ft. up to and including 34 ft. the top of the curbs and the center line shall be at the same elevation. For roadway widths ranging from 34 ft. up to and including 44 ft. the top of the curbs shall be 0.1 ft. lower than the center line. For roadway widths ranging from 44 ft. up to and including 54 ft. the top of the curbs shall be 0.2 ft. lower than the center line, and for roadway widths ranging from 54 ft. up to and including 64 ft. the top of the curbs shall be 0.3 ft. lower than the center line.

The elevation of the intersection of the curb tangents shall be determined from a point immediately opposite on the center line of the wider street or the street traversing the shorter block, if they are of equal width, subject, however, to the same correction in elevation between the top of the curbs and the center line as herein provided.

9. Depth of Gutters.—Whenever practicable a standard depth of gutter of 0.4 ft. shall be used.

10. Curb Grades at Corners.—The tangents in the curbs shall be graded uniformly between the elevations established for them at the boundaries of the building-line platform and at the intersection of the curb tangents. The curve formed in the curb joining the tangents shall follow a uniform grade between the elevations of the curb tangents at the points of curve.

11. Grades between Platforms.—The grades of the center line and of the curbs between the elevations computed at platform intersections, or between a platform and an intermediate established elevation, shall be uniform.

CHAPTER VII

THE CONSTRUCTION AND MAINTENANCE OF EARTH ROADS

An earth road is one that utilizes the natural soil of the right-of-way for a roadway surface. It is constructed in such a manner as to secure the maximum serviceability obtainable, with the particular kind of soil, under the climatic conditions that prevail in the region. Since soils are of so many kinds, the characteristics of earth roads may also be expected to vary greatly from place to place and particularly will they reflect the effects of climatic conditions. The problem of the road builder is to secure the most serviceable road that is possible, under the conditions that exist at the site of a proposed improvement, without adding any kind of wearing surface. To accomplish this he must understand the behavior of various soils and seek to make the most out of the situation that confronts him.

The earth road at its best is very susceptible to climatic influences, especially precipitation and freezing. The engineer's problem is to forecast, so far as he is able, the effects of climate upon the roads he plans to improve, and to construct the road in a manner well calculated to minimize the effects of climate. Fortunately, climatic influences and soil conditions are easily determined in the area encompassed by the ordinary highway improvement project, but plans that are satisfactory in one locality are not necessarily suitable in some other far-away district. The important thing is to know what devices are available to the road builder to minimize each kind of climatic influence, if any successful method has been devised. In many instances entirely new schemes must be introduced to care for conditions that are without precedent.

The earth road is sometimes graded and drained, as the first step in the construction of an intermediate- or high-type road and in that case the design of the earth road will be based on the principles that would apply to a high-type road. That phase of earth-road construction will be introduced occasionally in this chapter.

General Characteristics of Soils.—From the road builder's standpoint there are certain characteristics which are common to many soils, although these soils differ very widely from the agriculturist's standpoint. Certain broad principles of highway construction can be laid down that can be applied with some modifications to all soils in each group.

The names given to the various kinds of soil by the scientist often differ from the colloquial name, and the local name given to the soil in one community may differ from the local name given to the same soil in some other community. Nevertheless, since soil is the material which will be used by the road builder in his construction, some understanding must be had of the characteristics and behavior of these materials.

For this purpose soils may be divided into two groups; which are referred to as "clays and loams," since these terms are more commonly used by the layman than the more scientific designations.

It should be borne in mind that the line of demarcation between these two groups is not clearly drawn. They shade into each other, and many types will be encountered which could not readily be placed in either.

Clay.—The name "clay" is herein given to those soils which possess dense, tough and relatively impervious structure. These soils are black, yellowish, or reddish in color; are exceedingly sticky when wet, absorb water slowly, and retain it tenaciously.

A road surface constructed on such a soil, when once firmly compacted, turns water readily, softens from the surface downward somewhat slowly, but when permeated becomes very sticky, balling up on the wheels of vehicles in large masses; dries out slowly, is very tough when partially dry and, during the summer months, bakes into a hard crust which is exceedingly difficult to handle with any ordinary earth-working machinery.

These soils cannot be dragged when wet as they rarely become sufficiently plastic to work with a drag. On the contrary, the dragging must be done after the soil is in a crumbly condition. If an attempt is made to shape a road of this type of soil with a blade grader in the summer months, it is found that the material can be moved only with considerable difficulty, and if it is loosened with a plow, it breaks up into large pieces which are so hard that it is almost impossible to pulverize them and smooth the surface down to a passable condition.

These characteristics exist to a large extent in all soils of this general type, and present a distinct problem in earth-road construction. The degree to which the characteristics are found may vary in individual cases.

These soils also have a distinct characteristic as regards drainage. On account of the density and close texture of the soils, water permeates them but slowly, and underground drainage is much less effective than on porous types of soil. Tile drains along roads of this type of soil remove the water from the soil very slowly and it is a serious question as to whether the tile is worth while so far as its effect in removing ground water is concerned. These types of soil are also quite likely to lie in strata between which underground water is flowing. The seams often lie near the surface of a highway, and the water which is flowing between the layers will in these places work out to the surface causing mudholes, commonly called "seepy" places. When such conditions are encountered underground drainage is essential, but the tile must be laid so as to intercept the flow of water between the strata and carry it to the outlet, and thus prevent its coming to the surface of the road.

DESIGN

Cross-sections.—A typical cross-section for an earth road is shown in Fig. 47. The width of roadway will be a minimum of 20 ft. and a maximum of 30 ft. on roads of this class, depending upon the importance of the particular highway. It is to be understood that this discussion applies primarily to roads that carry insufficient traffic to justify any very elaborate construction, nor will the road be surfaced with gravel or other similar materials.

No guard fence is indicated and ordinarily none would be used except at particularly dangerous places such as high fills or fills on curves. Generally, guide signs are installed on earth roads that are used for long distance travel, but if the road is local in character, as is the usual situation, guide signs would be omitted. Warning signs at railroad crossings and other dangerous places should be installed as a matter of course.

Snow and Water.—The most serious problem is encountered in the humid areas of the world where the effect of water on the soil must be combatted. So far as the construction of roads is concerned, provision of ample surface drainage and the building

up of the berm above the influence of ground water, offer the most reliable means of minimizing the effects of precipitation.

Where the precipitation is in the form of snow, the avoidance of cuts which will fill with snow is sometimes feasible, but more often it is not and a snow fence will be of some help. In prairie country in the colder areas the quantity of snow may not be large, but it drifts continuously through the winter months, and shallow cuts will be refilled as rapidly as cleared. In such areas the snow problem can be minimized by constructing the road to a grade line somewhat above the general level of the adjacent land. The snow will then blow off the road instead of onto it. A high

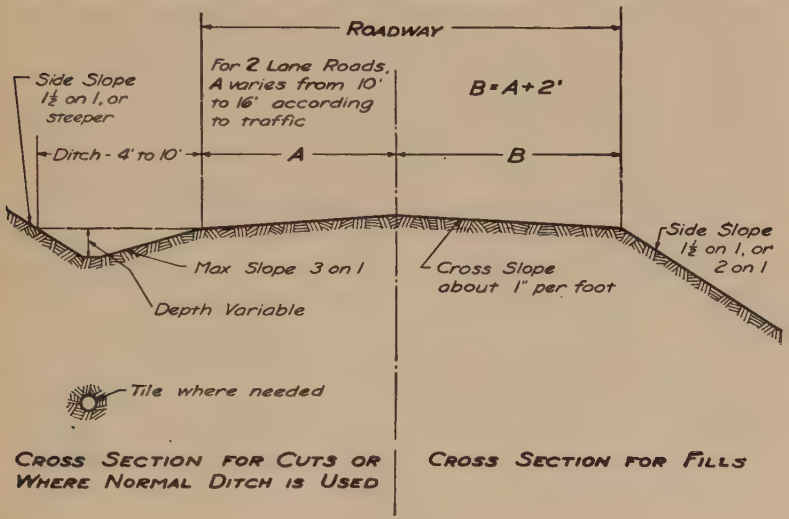

ROADWAY
Side Slope 1½ on 1, or steeper
For 2 Lane Roads, A varies from 10' to 16' according to traffic
B = A + 2'
Ditch - 4' to 10'
A
B
Side Slope 1½ on 1, or 2 on 1
Max Slope 3 on 1
Depth Variable
Cross Slope about 1" per foot
Tile where needed
CROSS SECTION FOR CUTS OR WHERE NORMAL DITCH IS USED
CROSS SECTION FOR FILLS

FIG. 47.

grade line is desirable in such areas from the drainage standpoint in any case.

Sand Drifts.—The method employed for minimizing snow difficulties is effective in desert and near-desert areas where the sand drifts as much as does the snow in the cold regions. If the road is kept high enough the sand will blow clear of the road. In such areas, cuts should be avoided at all costs.

Swamp Roads.—Swampy areas are encountered in connection with road building in many parts of the world and if the road is to be surfaced with natural soil brought in from borrow pits, there are two plans of construction from which to choose the one considered the better for the project in hand.

The older and more widely used method is to float the road crust on the underlying unstable soil by means of a mat of logs or brush, the old familiar corduroy method. This method is also often employed for roads to be surfaced with gravel. On top of this mat there is placed a layer of soil that is thick enough to provide a smooth surface. Unless the cover is a mixture of soil and gravel it will probably soften sufficiently at times to permit wheels to cut through to the mat. At such times the road is, of course, well nigh impassable to motor traffic, and is anything but satisfactory for animal-drawn traffic; but this cannot be avoided with the earth-covered corduroy.

Another method of constructing roads through swamps is to fill across the swamp, settling the fill by means of explosives so that the embankment rests on the stable soil which lies below the water and the plant growth that constitutes the swamp.[1] Sometimes the depth is so great that the cost of filling is prohibitive but in many cases the swampy deposit is relatively shallow, and this method is quite feasible. The method of settling is simple, although good judgment is needed in locating and charging the holes. The general plan is to dump fill material into the swamp, bringing the road embankment approximately to grade. Holes are then cut into the fill with an earth auger, and charges of dynamite placed at the bottom of the layer of freshly placed fill. When these are exploded the blast forces the soft material from under the new fill and allows it to settle down onto stable gound. A few trials will show how the charges should be placed and the best explosive to use. Commercial 40 per cent dynamite is used quite successfully.

GRADE REDUCTION

When the design provides for lowering the grade on a section of road, certain preliminary work should first be completed. If there are weeds, brush, or trees on the portion of the road to be graded, these should be cut away or grubbed out and the resulting debris burned. It is especially undesirable to leave under a fill quantities of organic matter, because it will decay and cause unequal settlement, and may lead to under-cutting from

[1] Riedesel, P. W., "Accelerating Fill Settlement by Means of Explosives," A Thesis submitted to the Faculty of Iowa State College in partial fulfillment of the requirements for the Professional Degree C. E. (1928).

water that works under the fill where it is porous from the decay of organic matter.

If fills are made on side hills where the cross-slope is steeper than 4 on 1, provision should be made to insure a bond between the new fill and the old ground. If the existing soil is porous and the slope does not exceed 3 on 1, this can be accomplished by plowing a series of furrows about 1 ft. apart, parallel to the center line of the fill. For dense soils or slopes greater than 3 on 1 the area to be covered by the fill should be graded to a series of horizontal benches about 4 ft. wide. After this preparation is completed the fill may be placed in a series of horizontal layers not over 2 ft. thick.

When the fill is constructed on a road that has a cross-slope flatter than 4 on 1, the new material may be placed without special preparation of the site, except to remove the vegetable matter. For fills of this class it is undoubtedly advantageous to place the fill material in layers not exceeding 2 ft. in thickness. The teams and scrapers will compact the material as they travel over it, and the fill that is built up will not settle excessively. Some engineers require that each layer shall be rolled before the succeeding layer is placed, but it is doubtful if there is enough benefit from the rolling to compensate for the cost. If fills less than about 2 or 3 ft. in height are to be constructed and a hard surface of some kind is to be built immediately, it is probably advisable to place the fill in thin layers, and roll each thoroughly.

Prevailing practice in earth-road construction is to permit the fill to be placed without restrictions as to the thickness of the layers, and without rolling. Suitable provision must be made for probable shrinkage of embankment in any case.

Blade Grader Work.—The blade grader is used mainly for work involving the moving of earth from the edges of the road to the middle to form the typical road berm. This machine is not efficient for moving earth lengthwise of the road, except for short distances, and then only when small quantities are used to fill occasional low places.

The blade grader favored for construction work is a heavy machine with a blade 12 ft. long. The power is a tractor of the size known as the "ten-ton," by which is really meant any one of a number of gasoline-engine-powered tractors weighing from 7½ to 10 tons. The types with "caterpillar" tread are quite

generally favored, but other types are widely used. Often, two blade graders hitched in tandem are drawn by a single tractor.

Elevating Grader Work.—The elevating grader[1] is a combined excavator and loader which may be expected to load as much as 150 cu. yd. of material per hour, when working conditions are favorable, although the average operator probably does not load much over 100 cu. yd. per hour. It is an economical machine to use in grade reduction work if the cuts are long enough to enable the machine to operate without too much loss of time in turning. The grader is operated in a loop, cutting and loading along the parallel sides of the loop, and idling while making the turns at the ends of the cut. The most economical use of the elevating grader is impossible on loops less than 300 ft. long.

The present types of elevating grader take power from the rear wheels for the operation of the elevator belt. This is never very economical, but is practicable and dependable where the soil affords good traction. In wet or light soils there is a good deal of slipping on the part of the drive wheels, which reduces the output of the machine quite materially. There ought to be a motor drive for the elevating belt, and doubtless a machine with that modification will appear in due time.

The excavated material falls from the elevator belt into dump wagons for transportation to embankment. When a wagon is loaded the grader is halted until an empty wagon is in place, then moves forward until the load is completed and the cycle of operation is thus repeated. It will be apparent that good management is necessary to insure the efficient operation of an outfit of this sort. The more salient points to take into consideration are the following:

The elevating grader should not be adopted for jobs where the cuts are so short that a high percentage of time will be required in turning at the end of the loop.

The grader should be provided with ample power. If animal-drawn, at least twenty good horses should be used. If tractor-drawn, the "caterpillar" type should be used and its speed should be adjusted to the grader which ought to be hauled at a speed of $2\frac{1}{2}$ to $2\frac{3}{4}$ mi. per hour.

The job should be carefully analyzed and the correct number of wagons secured, so that the grader does not lose time because

[1] HARRISON, J. L., "The Wagon and the Elevating Grader," *Public Roads*, Vol. 6, No. 2, April, 1925, p. 25.

of inadequate wagon supply. The correct number of wagons can be estimated on the basis of the length of haul, and the average speed of travel of team and wagon, which is about 2¾ mi. per hour, whether it be two horses on a 1½ yd. dump wagon or three horses on a 2-yd. dump wagon.

Scraper Work.—When grading involves removing material from short cuts and shallow cuts, the volume of earth to be moved from any one cut may be insufficient to warrant the use of the elevating grader, and some form of scraper will be employed. There are three types of scrapers that are available for this purpose.

The wheel scraper,[1] which has a capacity of about 10 cu. ft. is used when the excavated material is to be moved from 300 up to 1,000 ft. It is drawn by two animals and an extra team is used for loading. The soil must be plowed before it can be loaded and the common practice is to plow two furrows, then remove the loosened material, and repeat. Efficiency of use depends upon securing a full load every time, and keeping the scrapers moving in a loop of the minimum length that will deliver the material; and especially to adjust the loading and dumping places so that the length of the loop does not vary too much.

The fresno[2] scraper is used when the haul is less than 500 ft. and especially for loops of not over 200 ft. The scraper has a capacity of about 8 cu. ft. and is drawn by three animals. It is used for work similar to that for which the wheel scraper is employed, but on shorter loops.

Other forms of slip scraper built to be drawn by two horses are used for the same class of work.

Steam-shovel Excavation.[3]—Where heavy grading is being done so that an outfit can be used continuously for a long time without frequent costly moves, the steam shovel is economical. A standard railroad outfit would be employed for very heavy work, and the materials handled in dump cars on the industrial railway. For lighter work the traction type of shovel would be more satisfactory, and the earth hauled in horse-drawn dump wagons.

[1] HARRISON, J. L., "The Economical Use of Wheel Scrapers," *Public Roads*, Vol. 5, No. 10, December, 1924, p. 16.

[2] HARRISON, J. L., "The Cost of Grading with Fresnoes," *Public Roads*, Vol. 5, No. 8, October, 1924, p. 10.

[3] ALLEN, T. WARREN, "Power Shovel Operation in Highway Grading," *Public Roads*, Vol. 8, No. 12, February, 1928, p. 251.

RESHAPING AND LIGHT GRADE REDUCTION

Elevating Grader Work.—If a road is designed in accordance with the usual practice, particularly as regards cross-section, the elevating grader can be used to good advantage in the construction, even though no extensive grade reduction is involved.

In general, the work to be done consists in rounding up the traveled portions of the road with material obtained from the side ditches. The best results will be obtained with this outfit in flat country or slightly rolling country, where sections a mile or more in length can be constructed at one time, thus obviating frequent turning of the outfit.

Before the grading is started the portion of the right-of-way upon which work is to be done should be cleared of grass, weeds, and brush. This may be accomplished by cutting off the growth and raking it into piles, and burning. When only a small amount of growth exists, it is sometimes cut off with the blade grader and pushed off the portion of the road upon which work is to be done.

Classes of Road Work for Elevating Grader.—There are two classes of roads encountered where the elevating grader has proven satisfactory for shaping operations:

1. Roads practically level, where the new grade line is parallel to the profile on the old road, there being only a few knolls to be removed.

2. Roads on which there are a succession of knolls, and consequently a succession of cuts and fills, most of which do not exceed about 2 ft. in depth.

Construction Methods.—In starting the construction, the first cut is taken at the shoulder line and the material thus removed is deposited near the shoulder line of the opposite side of the road, but in the roadway.

Stakes are set for the first cut so that the drivers can follow them conveniently. If the outfit is horse-drawn the stakes are set so that the tongue of the elevating grader will follow them. If the grader is drawn by a tractor the stakes are set so that the front wheel on the steering side will follow them. The exact distance of these stakes from the line of the cut will vary somewhat with the type of elevating grader used, and must be determined before the stakes are set.

The first cut is a light one, and usually one horse of the lead team follows the first furrow, and thereby guides the grader in

making the succeeding cut. If the grader is drawn by a tractor a side hitch is used so that the tractor will travel on the "land" side.

On roads of Class 1, the successive rounds of the elevating grader are made without reference to the slight knolls that occur, and the material deposited on the roadway on top of the knolls is hauled away by slips or wheelers while the elevating grader is completing its round. A suitable adjustment of the working forces can be made so that the slips or wheelers can keep up with the grader.

On roads of Class 2, teams with dump wagons follow the elevating grader, loading where cuts are to be made and dumping the materials in the fills, the elevating grader continuing its rounds and depositing directly on the road in the low places. Here again a suitable adjustment of working forces must be made so that the elevating grader will not have to wait for the wagons. It is more economical to construct a mile or more of road at a time than it is to turn the elevating grader constantly, as would be necessary if each cut were completed by itself.

As the elevating grader makes successive rounds it gets farther away from the center of the road, and, consequently, when it is at the deepest part of the ditch where the heaviest cutting is being done, the earth is deposited in the middle of the road where the greatest filling is necessary to give the crown.

The material deposited on the roadway will consist of many large lumps as well as of sods and fine material. To work this material down to a surface that can be traveled the lumps and sods must be broken up with a disc harrow until small enough to form a satisfactory surface. Often, the sods and weeds are collected by harrowing with a stiff-tooth harrow and thrown out with pitchforks.

To bring the surface to its final shape a few rounds must be made with a blade grader. Then after the first rain the surface is smoothed with a road drag. Constant dragging and frequent smoothing with a blade grader are necessary during the first year to keep the road in shape while it is becoming compacted by traffic.

Blade-Grader Work.—When the blade grader is used for shaping the cross-section, it is necessary to complete all grade reduction work before beginning the shaping. The grade reduction work is commonly performed with the wheel scraper,

fresno scraper or with the elevating grader as described in a preceding section. The elevating grader method is not common, however, because if the elevating grader is available at all, it is generally employed to the exclusion of the blade grader.

Having brought the road to the adopted profile, the blade grader is used to shape the cross-section. The first cut is made near the shoulder line and succeeding cuts farther out in the ditch, and the material thus excavated is dragged to the middle portion of the road to round up the roadway. Two graders hitched in tandem are sometimes drawn by one tractor, thus increasing the speed with which the work can be completed.

Maintenance.—It is to be expected that a newly constructed earth road will be unstable because of lack of solidity in embankments and lack of uniformity of texture in the soil exposed in the cuts. Weathering, settlement, and precipitation are continually at work and their effects must be counteracted by suitable maintenance. The work of maintenance must begin as soon as the road is placed under traffic and be continuous thereafter. The patrol system, supplemented by emergency dragging, seems to produce the most satisfactory results. Under this system a section of road is taken care of by a man who devotes all of his time to the duties incident thereto, and who will use the equipment selected as being the best adapted to the soil and climatic conditions.

In regions of high rainfall the log or plank drag will be used to smooth the road surface while it is wet, thus filling the depressions and serving to squeegee some of the water off the traveled part of the surface. This tool does not compact the surface to any considerable extent, nor does it move enough mud and slush to fill the larger depressions. Moreover, the traffic will disturb the smooth surface readily and seemingly undo all the work performed by the drag. Continued dragging as the road surface is drying will insure that when finally dry the surface will be fairly smooth. This method is particularly useful for roads that carry light traffic, and the soil is not too waxy and tough when wet. Some soils can scarcely be handled until they reach the crumbly stage of drying and some others cannot be handled by the drag after they begin to dry out, because they are so waxy that the drag cannot move enough material to really smooth the surface.

The drag is not used on dry road surfaces because it is not adapted to loosening firm or partly packed material. At this

stage the blade grader or some type of maintainer will be more effective than the drag. Light blade graders have come into wide use for work of this character.

MACHINERY USED FOR EARTH-ROAD WORK

Picks, Mattocks.—These tools are used for grubbing, dressing up earthwork, and for similar familiar purposes. They are used so commonly and are so well known that no comment is necessary.

Shovels, Spades.—For moving loose earth or slightly tamped material, the ordinary No. 2 shovel is commonly used. It is not an economical tool for digging hard earth, and either the ordinary flat spade or the solid-back tile spade should be used for that purpose.

Plows.—The plow used in highway construction is subjected to very severe service and must be strongly made. It should have a long iron-shod beam with a shoe and the width should not exceed 10 in. It should be strong enough to stand up when drawn by a tractor.

Rooter Plows.—If old gravel roads or roads containing stony material or hard-baked earth are to be loosened, the rooter plow is the most suitable. It is heavy and often has a cast beam. For breaking the soil it has a stout metal point, sharpened on both ends, which can be reversed or the working length adjusted.

Harrows.—For breaking up the sods and large lumps of soil after a road has been graded, a disc harrow heavily loaded is most commonly used, but a stiff-tooth iron harrow may be satisfactory if the soil is not too thoroughly dried out.

Slip Scrapers.—Slip scrapers are suitable for moving rough materials, especially earth, if the haul does not exceed about 100 ft. They are well suited to small work since they require no loader other than the driver, and no dumper. The slip scraper may be used in connection with an inclined chute for loading crushed stone or gravel from a storage pile into wagons.

Fresno Scrapers.—The fresno scraper is used widely in the west and middle west and, to a less degree, elsewhere for the same purposes as the slip scraper. It is more efficient than the slip scraper and is suitable for hauls up to 500 ft.

Wheel Scrapers.—The wheel scraper is used for general earth-moving work where the haul is 300 ft. or more, but is not efficient if the haul exceeds 1,000 ft. It is made in several sizes, ranging

in capacity from about 5 to 16 cu. ft. The larger size is preferable on heavy work, as a "snap" team must be employed in loading in any case. A loader and a dumper must always be employed, and usually the material to be moved must be loosened with a plow before it can be loaded.

Road Graders.—The road grader is the most commonly used and best-known machine used for general highway construction, and needs no description. The later models have many devices for convenience in adjusting the cutting blade for various kinds of work, and most of them can be steered by the operator so that they are not entirely dependent upon the accuracy with which the tractor hauling them is steered. It should be noted that these machines move earth by sliding it along the surface of the road, and it is, therefore, better adapted for light or medium work than for construction requiring large amounts of material to be moved.

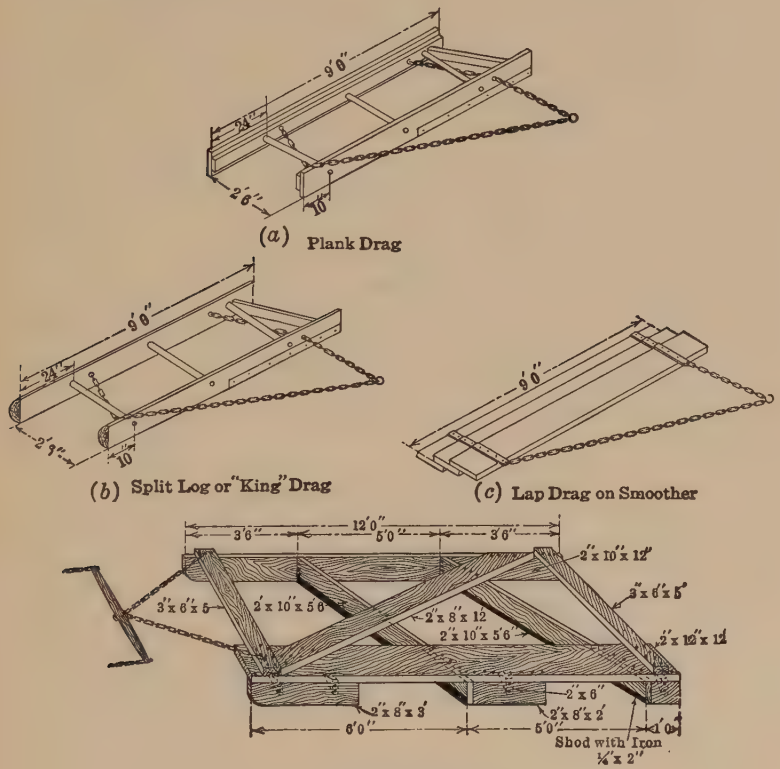
Elevating Graders.—The elevating grader is so arranged that a plow loosens the soil and deposits it upon a moving apron, which in turn deposits it in a wagon or upon the road surface as desired. The elevating grader is used widely in grade reduction work for loading the dump wagons. It is also used in earth-road construction for crowning up the middle part of the road and for general earth-road construction, depending upon size and kind.

Levelers.—In recent years there has been developed a new type of machine designed to perform the work of a light grader and road drag at one operation. In brief, the leveler consists of a truck to which is suspended a pair of long blades which form a V lying on the road with open end to the front. The width covered at one trip is often as much as 30 ft., and the action of the machine is to draw a little material from the sides of the road to the middle, smoothing out all depressions as it does so. The machine is well adapted for the purpose, but up to this time it has not been built with blades that can be adjusted to the curved cross-section usually specified for earth roads. It also has a tendency to leave a ridge of loose material in the middle of the road.

Maney Grader.—The Maney grader is a wheel scraper with four wheels, having a capacity of about 1 cu. yd. It is used for the same kinds of work as the wheel scraper.

Dump Wagons.—A great many types of dump-bottom wagons are manufactured, and these are used for handling all sorts of

road materials. They are very satisfactory for hauling earth on grade-reduction work if the haul exceeds about 1,000 ft., and are also used in connection with the elevating grader on earth-road construction. They may be had in capacities from 1 to 5 cu. yd. as desired, but the 1½- or 2-yd. sizes are best adapted for highway construction.



(*d*) Road planer

FIG. 48.—Types of road drags and a road planer.

This type of wagon is commonly used for hauling broken stone, sand, gravel, and other similar surfacing materials.

Trucks.—Trucks with side-dump and end-dump bodies are available in many types and capacities. These are used for hauling excavated materials in road construction, and are rapidly superseding the animal-drawn dump wagon.

Road Drags.—The first drags used were the split-log type, developed and made a factor in road maintenance by D. Ward

King. This type of drag is variously constructed, but except in details is always much the same. It consists of the two halves of a log about 10 in. in diameter, held about 2 ft. apart by suitable cross-pieces and is provided with a chain for the hitch. The length is from 6 to 9 ft.

The plank drag is similar in form to the split-log drag except that 3- by 12-in. planks are used, instead of the halves of logs. It is recommended that the front log or plank be shod with a metal strip for at least half its length, the metal strip extending from the end of the log that is run foremost.

The lapped-plank drag consists of three or four 2-in. planks, 12 in. wide, nailed together with the edges overlapping. This kind of drag acts more as a smoother than as a drag, but is very satisfactory for clay soils.

Many steel drags are now offered, and they are built in the same general way as the plank drag, except that all parts are of metal. Most of them are constructed so that the blades can be tilted to any desired angle.

A new type of drag known as the Minnesota road planer has been devised which has features that give promise of great usefulness.

A FEW ROAD DRAGGING RULES[1]

The purpose of road dragging is to "puddle and smear" the surface, thus forming a wearing coat which is practically impervious to water. Dragging the road to produce smoothness and a standard crown are essentially a part of the purpose, but this must not be confused with the real purpose, or each successive dragging will do actual damage to the road, although not apparent at first sight.

Water will pass through ordinary soil quite readily. If the same soil be dampened sufficiently so that the surface may be puddled and smeared, thus closing the pores, this soil will prove to be quite impervious to water. Consequently on an undragged road or a dragged road in a dry condition, by thus opening the pores and forming dust, the dry powdery surface of the road will absorb the rains, producing deep mud, while on the other hand, a road puddled and smeared to a standard cross-section will cause the rain waters to follow lines of least resistance and flow to the gutters. An extremely wet soil will not pack, but will

[1] Abstract from *Canadian Engineer*, Vol. 53, No. 2, July 12, 1927, p. 128.

squash under the traffic, but, on the contrary, a medium damp soil will pack tightly under the traffic.

It is toward these more ideal conditions that we would work by observing the following rules:

Use a light drag, hauled at an angle to the road so that a small amount of earth may be hauled to the center of the road.

Drive at a walk and watch the condition of the road ahead of the drag so that you may correct the faults.

Always ride the drag; do not walk.

Begin on the outside and return on the opposite, unless the road is peaked and needs flattening.

Fill all the perceptible ruts before they are deepened.

Cut the humps to a level section.

The amount of earth carried along by the drag, and the nicety in cutting and filling, are controlled by the driver.

To make a drag cut deeper the driver should throw his weight upon the one foot near the cutting or forward corner of the drag.

The drag will cut less deeply as the driver's weight is shifted toward the rear and opposite corner of the drag.

Do not leave a ridge in the center of the road; flatten it out with the drag set straight across the road.

Drag the road immediately after a rain unless the mud is in such condition that it will stick in the drag.

The right time to drag is when the road is wet.

Do not drag a dry road.

When the surface crumbles under the drag, the road is too dry to drag. The dust thus formed may blow away thus robbing the road of its cementing material.

Drag when the mud can be spread as a mortar, forming a sealing coat.

Drag the road late in the season in order that it may freeze with smooth mortared surface.

Don't get discouraged when traffic seems to ruin what you wish to accomplish by dragging—each succeeding rain will penetrate less deeply until you are master.

Problems

1. Furnish each student a plan and profile for about 1,000 ft. of a road-grading job and have them indicate on the plan the location and markings on the slope stakes at one station of the fill section and one station of the cut section.
2. The plans for a road-grading job provide for the cross-section on embankments to be 30 ft. wide on top, to be flat on top and to have side slopes of 1½ on 1. At a station where the site is about level the fill is to be 10 ft. high. Draw sketches showing the final cross-section and by dash lines indicate the limits of the embankment as placed. (*a*) fill material, average soil; (*b*) fill material, 80 per cent blasted rock, 20 per cent soil; (*c*) fill material, 70 per cent soil, 30 per cent blasted rock.

3. Prepare a set of instructions to be given to patrolmen explaining how they are to maintain earth roads.
4. Prepare a set of instructions to a blade-grader gang explaining how they are to reshape an earth road.

CHAPTER VIII

SAND-CLAY ROADS

The name sand-clay is given to a type of road surface that consists of natural or artificial mixtures of sand, and clay, loam or gypsum, or of all of these materials. Such surfaces are constructed on clay, loam or gumbo soils and on deep sand. The character of the sand and of the soils encountered varies so greatly that it is impossible to lay down specific rules and proportions for the construction that will have universal application. Surprising results are often obtained with most unpromising materials and under unscientific methods of construction, yet in general the best results are obtained when a few well-established principles are observed. The methods of construction and the combinations of materials that have been most successful and the principles involved may profitably be studied.

The essential requirements for success are that the materials be reasonably suitable in character, and that they be thoroughly mixed. The aim is to secure on the surface of the road a layer or crust which is made up of sand into which has been introduced a binder of clay, loam, or gypsum and clay. The amount of this binder needed is approximately that which will fill the voids in the sand, and as a rule the more nearly that amount is used, the better the results will be. Lumps of clay or other binder are to be avoided and thorough and persistent mixing is, therefore, imperative. If natural mixtures of sand and clay are used, these will rarely be uniform and after they are spread on the road they must be mixed to secure a homogeneous layer.

TYPES OF SOIL

Gumbo.—This soil is the familiar black or yellow waxy soil found in widely scattered localities throughout the United States. It is exceedingly fine-grained, dense and sticky, and when wet rolls up on the wheels of vehicles until they become solid balls of mud. It is broadly classed as a clayey soil.

Slaking Clay.—This type of clay is found mixed with a varying percentage of sand, is somewhat coarse-grained and becomes soft and mushy when wet. It is a yellow to reddish color and of varying degrees of stickiness. Since it is not uniformly sticky and is unstable when wet, it is not the best material to use on a deep sand soil, but where it is the only material available, it is used with more or less satisfactory results.

Semi-plastic Clay.—This material is of a gray, yellow, or reddish color, of fine texture, tough, dense, and in physical characteristics resembles gumbo. Since it is sticky and fairly stable when wet, it is a good binder for a sand road, but on account of its physical characteristics it is more difficult to handle than the slaking clay.

Sand-clay Soils.—In some localities there is found a soil which consists of a natural mixture of sand and one of the types of clay, proportioned about right for road surfacing. If deficient either in sand or clay, the mixture can be adjusted during the construction by the addition of the material that is lacking. The soil is rarely uniform in composition, and usually must be mixed on the road to secure a homogeneous surface layer.

Loam.—Loam is a brown or black, porous, coarse-grained soil containing varying percentages of sand. It is not a good material for road surfacing on account of its poor bonding properties and its lack of stability, but it is sometimes the only material available in a region of sand roads. Its use is advisable only under such conditions.

Sand.—The sand soils vary greatly in fineness and clay or loam content. When deep and free from clay or other bonding material they become loose when dry and in this condition on a highway they make a surface of very high tractive resistance. If on a low-lying road so that they are constantly water-saturated, they remain fairly stable, but in such instances are not of interest in this discussion.

Gypsum.—In a few localities, notably western Kansas, there are deposits of a mixture of gypsum and clay, together with more or less sand and gravel. The gypsum serves to augment the bonding effect of the clay, and these mixtures when incorporated with a sandy road make an excellent sand-clay, or as commonly designated, gypsum road.

SAND-CLAY CONSTRUCTION ON GUMBO, CLAY OR LOAM

When the natural soil is gumbo, clay or loam, the general method of construction is identical but varies in detail. The object sought is to secure stability by the addition of sand or a sand-clay mixture.

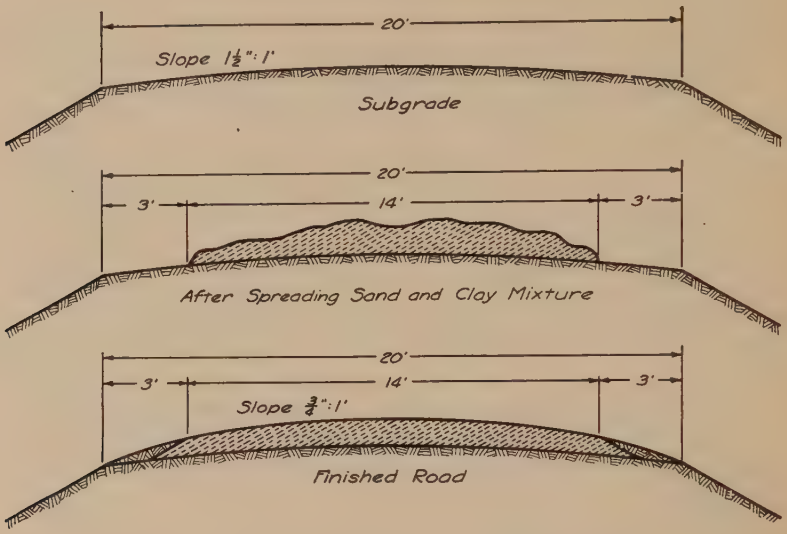
I. By Addition of Natural Sand-clay Mixtures.—The road to be improved is graded so that proper side ditches are obtained. The middle portion is made about flat, as shown by Fig. 49. Upon this section the natural sand-clay mixture is spread in a layer about 10 in. thick, at the middle and 6 in. at the edge, the width being from 10 to 16 ft. The sand-clay mixture is smoothed with a grader and as soon as it is thoroughly soaked by rains it is harrowed to break up the lumps and mix the materials until a layer of uniform texture is obtained. The road is then reshaped with a blade grader and is ready for traffic. If the natural sand-clay mixture is deficient either in clay or sand, the material that is lacking is added before the mixing is done.

II. By Addition of Sand.—The roadway is shaped as described before and the surface to be covered with sand is plowed to loosen it. The sand is spread on the surface to a depth of about 6 in. While still dry the road is plowed again to mix the soil and the sand. After the plowing the mixing is completed with a disc harrow and this can best be done when the road is wet. After a thorough mixture is obtained, the surface is shaped with a grader and is compacted by traffic.

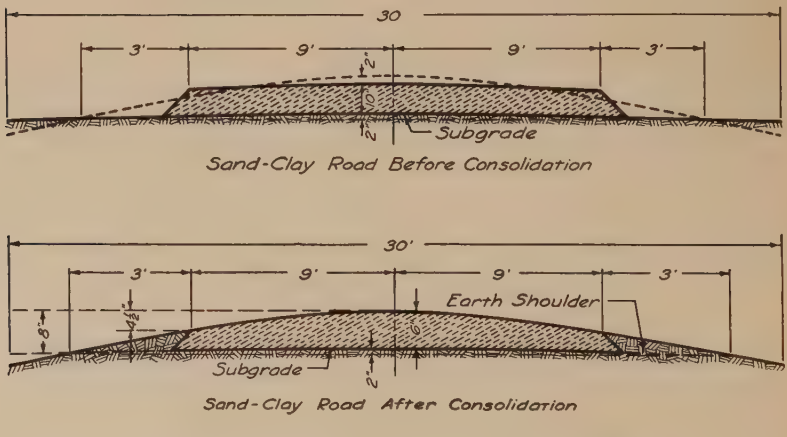
The same results are obtained by spreading the sand or fine gravel on the road in a layer 3 or 4 in. thick and allowing traffic to use it. When the road is soft after rains, the sand will be mixed with the soil and if it appears that additional sand is needed, it is added. This method is less effective than the one first described, but in time a serviceable road will result if it is given proper attention and is kept free of ruts.

SAND-CLAY CONSTRUCTION ON SAND

I. By Addition of Natural Sand-clay Mixtures.—The sandy road is shaped to a slightly crowned section with shallow ditches and with a nearly flat section in the middle portion upon which the clay mixture is to be placed. The sand-clay mixture is then spread on the sand in a layer about 10 in. thick at the middle and 6 in. thick at the edges, and when wet is thoroughly mixed



SAND-CLAY CONSTRUCTION ON CLAY, GUMBO OR LOAM



SAND-CLAY CONSTRUCTION ON DEEP SAND

FIG. 49.—Cross-sections for sand clay roads.

with a harrow and smoothed with a grader. If the sand-clay mixture is deficient in sand, the defect is remedied by throwing on sand from the roadside. The mixing is done merely to secure uniformity of the surface and not to mix the surface material with the sand.

II. By Addition of Clay.—The amount of clay that should be added is theoretically the amount necessary to fill the voids in the sand in a layer the desired thickness. The voids can be determined by the water-displacement method which will indicate roughly the amount of clay to use. A somewhat larger proportion of clay of the slaking type is needed than of semi-plastic clay. The use of too much clay should be carefully avoided. Enough clay is spread on the surface of the sand road to fill the voids in a layer about 10 in. thick. This is then mixed with the sand by plowing and discing until a thorough mixture is obtained and the mixing must be done while the road is wet. This is

FIG. 50.—A well-built sand-clay road about five years old.

the vital part of the construction and is a tedious and disagreeable job but the success of the construction depends upon the thoroughness with which it is done. The surface is then smoothed with the blade grader and is compacted by traffic.

Where no clay can be found to mix with the sand and no natural sand-clay mixtures are available, loam is used instead. The construction is carried out as just described. The results to be expected are not as good as if proper materials were available but a crust is formed that will be serviceable except in long-continued dry weather. It is apt to break through to the sand if not made of ample thickness.

Gypsum Roads.—This type is almost always constructed on sandy soils and the method of construction is the same as described for the placing of natural sand-clay mixtures.

In all sand-clay and gypsum construction, thorough mixing and careful proportioning are essential if first-class roads are to result. As the road is opened to traffic it is not a finished product but will require smoothing with the grader or drag at intervals for a year or more. Quite often it will be apparent as time goes on that more sand or clay, as the case may be, is needed, and such should then be added a little at a time until the road becomes smooth and firm.

Not infrequently the ingredients for a sand-clay road are thrown together in a haphazard manner, the mixing being left to be done by traffic and the road receives little care, and in spite of the neglect becomes a fairly good road. The time and expense necessary for the best results are, however, fully justified by the better service the road will give.

Characteristics.—The sand-clay road is resilient, dustless, and will be smooth if properly built. It becomes only slightly muddy on the surface, is serviceable for moderate traffic, and requires little care after it finally becomes solid. It may be damaged by traffic during long-continued dry weather. The cost ranges from $1,500 to $2,500 per mile for roads 26 ft. wide, depending as would be expected on the availability of materials and the cost of labor.

Problems

1. Estimate the quantity of top-soil (natural sand-clay mixture) required for 100 ft. of road constructed to the cross-section shown in Fig. 49.
2. A sand-clay surface is to be constructed in accordance with the cross-section shown in Fig. 49 by adding clay to a road surface of deep sand. Estimate the amount of clay required for 100 ft. of road. Assume that the sand on the road is of such a character that a good surface is secured with a mixture in which the clay is 35 per cent. by weight.
3. Outline the tests that should be made on available materials to determine the proper mixture to use in problem 2.

EXAMPLES OF GOOD PRACTICE

A. An Investigation of Sand-clay Road Surfaces[1]

Conclusions

A study of nearly a thousand analyses, in the laboratory, and a comparison of the results attained with such materials in actual

[1] Abstract of a paper by John C. Koch, Pro. Am. Soc. Civil Engrs. Vol. XL, p. 269.

road construction, have led the writer to formulate the following tentative, working rules for examining sand-clay mixtures and as a basis for making up proper combinations for artificial mixtures:

1. The total relative sand content, disregarding the size of the sand grains, is not a criterion of the value of the material.

2. The sand smaller than No. 60 is of little value in the mixture; that smaller than No. 100, except in very small quantities, is detrimental.

3. The greater the proportion of coarse to fine sand the harder and more durable will be the road surface.

4. For the best possible results with sand-clay mixtures the sand smaller than No. 10 and larger than No. 60 should not be less than 45 per cent nor more than 60 per cent, by dry weight, of the entire sample. In addition, the sand smaller than No. 10 and larger than No. 60 should be composed of about equal parts of Nos. 20, 40, and 60. The total sand content should in no case exceed 70 per cent by weight of the total sample.

5. Test cylinders of the sand-clay mixture, 1 in. in diameter and 3 in. long, should, when thoroughly dried in air bath at 100°C. take at least 2 min., when immersed in water at 21°C., to crumble down to the natural slope of the material, and preferably should take 6 min. If the cylinder fails in this test it should be regarded with suspicion. If the sand analysis is poor and the cylinder test is also poor the material is not worth using.

6. Test cylinders, made from the clay removed from the sample, 1 in. in diameter and 3 in. long, should take at least 2 min. to crumble down to the natural slope of the material when immersed in water at 21°C. If it fails in this test, but passes the test of the preceding paragraph, it may be used, but it indicates a poor quality of binder.

The material comprising the top soil of cultivated land, when composed of the proper combination of sand and clay, has probably been more thoroughly weathered and therefore is less likely to wash and disintegrate when placed on the road. Cultivation has also produced a more thorough and complete mixture of the two materials.

METHOD OF CONSTRUCTION

Mr. Koch recommends the following method of construction:

The subgrade of the roadway is brought to a level or slightly convex cross-section. The sand-clay is then placed in a contin-

uous layer, from 10 to 12 in. thick, the material being spread as fast as delivered and not dumped in piles here and there. This layer is spread for a width of 20 ft. for a nominal 30-ft. roadway. After a sufficient quantity has been placed in this manner, an ordinary road machine is drawn along the ditch line cutting about 4 in. deep at the outside, and the blade is set so as to cast the material from the ditch against the edge of the sand-clay layer. In this way a shoulder is built up against the sand-clay to hold it in place. This also shapes the ditch. After both sides have been thus shaped the road machine, in successive passages, rounds up the cross-section of the sand-clay so as to give proper crown to the roadway and a smooth line from the crown to the ditches. As soon as the road is shaped, traffic and the construction teams begin to compact it, and it rapidly becomes consolidated without the use of a road roller. As the consolidation progresses ruts are formed, and they should be filled and a proper cross-section maintained by the occasional use of the road machine for a period of about two months. Unless this is done the road surface will become rutted and rough, and eventually compacted with a concave crown which will prevent proper drainage. After the material has been consolidated into a hard mass the difficulty of securing a good cross-section is largely increased.

The cross-section which seems to have given the most generally satisfactory results is a parabolic form with a crown of ½ in. per foot, that is, for a roadway surfaced for a width of 20 ft. the crown would be 5 in., and the height of the center of the road above the ditch (for a road having a width of 30 ft. between ditches) would be 7.5 in. With steeper crowns than this it has been found that the surface cuts into a series of parallel ridges running from the wheel tracks to the ditches and making it very disagreeable for travel. If less crown is given the provision for wear is too small, and the drainage may not prove satisfactory after a comparatively short time.

For several months rains are apt to soften the top crust and cut up the smooth surface, but if patience is exercised and the road machine is used to maintain the cross-section properly it will be found that the puddling action of the traffic when the road softens is a great aid to final consolidation.

Construction with Artificial Mixtures.—From analyses made of materials proposed for use on account of accessibility and from a study of their sand analyses, the proper ratio in which two or

more materials should be mixed can be determined so as to secure the best possible results with the available materials. Three cases arise in which artificial mixtures are to be used:

1. Sand foundation, where clay is to be hauled and proper mixture made by disc plowing and puddling.

2. Clay foundation, where sand is to be hauled and mixture made as above.

3. Soil foundation, where both sand and clay are to be hauled and mixture made.

In any of these three cases the proper mixture of the materials and the puddling action of traffic are necessary to secure a good consolidation. It takes considerable labor to secure a satisfactory mixture, but, except for this, there is no essential difference in the fundamental principles applying to construction with either artificial or natural sand-clay mixtures. The use of the road machine to maintain the cross-section and the height of the crown should be the same for each type of construction. For the softer varieties of sand-clay the split-log and other forms of light drags may be used effectively in maintenance.

B. Georgia

Durability and Maintenance[1]

While the testimony of experience is ample that the better grades of these soil roads give most excellent betterment over a number of years, it is to be regretted that no specific records are available to connect that service and the period of their effective life with the exact traffic density endured. The large mileage of construction made and under use for 15 years by the counties carries very varying amounts of traffic. Conditions have not been favorable in the various counties for keeping accurate records of repairs and proper traffic census. In fact, most of this mileage has not received systematic maintenance. Satisfied with the improved service and urged by popular demand, the county authorities have generally proceeded to build other new roads with a minimum attention to the upkeep of those already built. Too often these roads have been allowed to wear out uncared for until rebuilding became a necessity. The state roads recently completed are in better case. They are being placed under constant patrol maintenance and in a few years

[1] Strahan, C. M., Univ. Georgia *Bull.*, Serial 326, June, 1922.

accurate data will be in hand to measure the effective life in relation to traffic density and annual repair.

If the writer may venture an opinion based upon observation, he would estimate that an effective life of 6 to 8 yr. may be expected from a well-cared-for Class A road of this type. The main roads of Clarke County were constructed with top soil in 1907–1908–1909. These roads have been recovered with soil twice since those dates. The latest recoverings were in 1920–1921. Such reconstruction consists in scarifying the bed, pulverizing the clods, and incorporating with the old material about 5 in. of new top soil. The roads in question have had intermittent repairs but have not received the attention of a constant patrol force. Similar conditions have existed in many counties. Judging from the above record an effective life of 6 to 7 yr. is shown accompanied by maintenance cost not exceeding $100 per mile and a rebuilding cost at the end of 6 or 7 yr. equal to about one-half of the original first cost.

For the state at large, it is thought that a 5-yr. average effective life is a conservative low figure under intermittent repair.

When built under more ample specifications of the State Highway Department and cared for steadily with the expenditure of $300 per mile, it is reasonable to expect at least 40 per cent increase in the effective life.

Many of these roads are carrying traffic of 300 to 500 vehicles per day including probably 5 to 20 trucks (1- to 5-ton capacity). The passenger auto traffic does little injury to them. The heavy trucks in wet weather develop any weakness in the subgrade support or where the soil layer has become thin. Where a full 10-in. bed was laid (packing to 6 in.) of Class A material, the truck traffic is sustained admirably.

Existing data of the State Highway Department indicate $300 per mile as a probable maintenance average per annum. Recent contract lettings have been made on the basis of 45 cts. per cubic yard for soiling, consolidated in place. The quantity per mile is taken at 3,200 cu. yd.; average haul, 1 mi.

Allowing for overhead and other costs, the unit figure per mile of $2,000 is deemed reasonable. Using the above assumptions, and accepting a 7-yr. effective life, the following analysis results:

Original cost of surfacing	$2,000.00
Repairs at $300 per year, 7 yr	2,100.00
Interest on cost at 4½ per cent., 7 yr	630.00
	$4,730.00
Less residual value of surface, 35 per cent	700.00
Total 7 yr. cost	$4,030.00
Distributed annual cost per mile	575.71

Similar analysis for subsequent 7-yr. periods assuming constant traffic density, will vary but little from the above distributed average.

High-grade pavements starting with a first cost of $22,500, rarely show a lower annual maintenance than $200 per mile. Assuming the extremely low depreciation figure of 2 per cent. per annum, such pavements will give a distributed annual cost of $1,662.50 per year, of which annual interest and repair comprises $1,212.50. The economic efficiency of these road soils is high under the traffic conditions in this state. Increased traffic density due to heavy-unit trucks would be reflected in the increase of annual upkeep and reduction in the effective life period. As compared with expensive pavements, these roads may be considered efficient until the effective life period is reduced to 3 yr. accompanied by an annual upkeep of $700 per year. Their residual value as subgrade for better pavement is large.

The chert and clay gravel roads represent a much larger average haul even when locally available; and hence their first cost can seldom be less than $5,000 per mile, and more commonly will run to $7,000. The maintenance will at least equal that of the soil road; but the effective life, if well maintained, will be longer. It may be taken at say 10 yr. A tentative showing is as follows:

Assumed first cost	$ 6,000
Maintenance, $300 or more	3,000
Interest, 4½ per cent, 10 yr	2,600
	$11,600
Less residual value (50 per cent depreciation)	3,000
Distribute annual cost	$ 860

At such figures the chert and clay gravel roads are highly efficient and can be wisely used until the distributed annual cost reaches $1,200. The writer presents the above discussions as a matter of opinion and judgment.

In all classes of these roads, the chief operations of maintenance can be performed by road machines and metal drags applied after rains. Class C roads while free from deep mud usually soften under long rains and invariably need reshaping after such periods. A three-way metal drag covering 12 to 16 ft. width is a very effective implement which not only smooths but can carry forward enough material to fill depressions of 4 or 5 in. and thus remove the undulations which tend to form on weak subgrades and on the softer road soils. Heavy road machines are necessary to shape the hard Class A roads and are most effective after long periods of rain. Lack of uniform mixing during construction shows itself in the formation of dust holes in dry weather. If this trouble exists over a long stretch, the best remedy is to scarify, remix, and add new material. Occasional holes can be cut into rectangular shape and filled with new material which is moistened and packed with a hand tamper. The maintenance organization should consist of patrolmen in charge of 8 to 10 mi. equipped with hand tools, wagon, and metal drag; and a tractor gang, covering periodically 50 mi. or more, which reopens side ditches, reshapes the crown, and rebuilds weak sections as needed.

The repair force should have access to supplies of good road soil at all times, and the contents of side ditches should be religiously carted off from the road. Many excellent soil roads have been greatly injured by the careless use of unsuitable soil in repairing, and particularly by spreading the silt and fine sand in the side ditch back over a good material on the wheel bed. For the larger repairs a caterpillar type of tractor has been found most useful. It not only furnishes ample power for plowing, scarifying, and machining, but aids wonderfully in pulverizing clods of the old beds when resoiling must be done. The state maintenance forces drag or machine all of the state roads after rains.

CHAPTER IX

GRAVEL ROADS

The term *gravel road* has for many years been used by the public to designate a wearing surface composed of natural gravel of some sort, or of a variety of analogous materials such as crusher-run or screened broken stone, slag, shells, and burnt shale.

The true gravel road consists of natural gravel, which may, or may not, be specially prepared for the purpose. There are two types of gravel road, which are differentiated by differences in

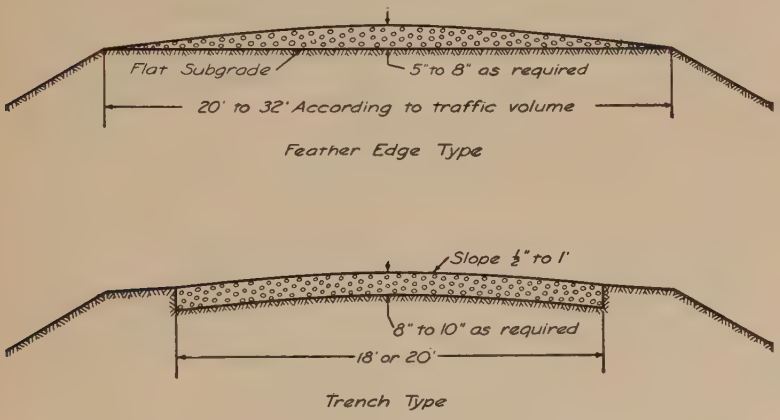


Fig. 51.—Typical cross-sections for gravel roads.

the materials of which they are composed, and the method of construction employed. These types are known as the *feather-edge* gravel road and the *water-bound* gravel road, respectively. The cross-sections usually adopted for these are shown in Fig. 51.

The gravel road is capable of carrying a considerable volume of traffic because it lends itself rather readily to a simple type of patrol maintenance, but under traffic exceeding 300 vehicles per day, will seldom hold up to maximum serviceability for more than a day or two after a careful smoothing, under the most favorable conditions. In dry weather or wet weather it becomes

very rough in a few hours after it has been dragged, the surface developing into a succession of transverse ridges, that are sometimes dignified by the name *rhythmic corrugations.*

On secondary roads, where traffic is an average of 200 vehicles, or less, per day, the gravel surface can be kept reasonably smooth at low cost and is a very economical and generally satisfactory type.

The water-bound gravel road is not widely used because the cost is considerably higher than that of the feather-edge type, and the durability perhaps not proportionate to the higher first cost. Where it is expected to employ the bituminous carpet coat for the maintenance of the surface, the water-bound type has a distinct advantage over the feather-edge.

MATERIALS

The natural gravels occur in many parts of the world and consist of deposits of partly rounded and smoothed fragments of rock, ranging in size from fine grains of sand to sizeable boulders. Usually there is some earthy material mixed with the gravel and sometimes the earthy material comprises a considerable percentage of the deposit. The portion of the material that will pass the standard No. 4 sieve, exclusive of the earthy material, is universally called *sand,* and the portion coarser than sand is variously called *stone, pebbles,* or *gravel,* except that when used for concrete this portion is usually called *stone* or *coarse aggregate.*

Gravel deposits differ widely in the relative proportions of sand and pebbles, the amount and kind of earthy material, and the character of the rock of which the fragments are composed. Deposits of fissured limestone, nouvaculite, or granite are sometimes called *gravel,* but in these the pieces are angular instead of rounded and such material is not true gravel.

The gravel road is usually adopted for a particular project, because gravel of acceptable quality can be obtained at low cost, or in the hope that local supplies can be utilized. The ideal road gravel consists of fragments of durable rock, well graded from coarse to fine, with at least 50 per cent, by volume, of sand, and contains about 15 per cent of clayey material to serve as binder. Durable roads can be constructed from a wide variety of natural gravels if proper methods are followed, but the more exacting the traffic, the greater the need to secure gravel approaching closely the ideal in properties.

Wearing Qualities.—The hardness and toughness of the stones in the gravel may be determined in the Deval machine in the manner in which similar properties of broken stone are determined. The results are neither as uniform nor as significant as for broken stone, but serve as a reasonably accurate measure of the value of the material. Quite often, individual stones in the lot tested are of some partially disintegrated material and lose a disproportionate amount during the test. A gravel containing a few stones of this kind would probably wear better in the road than the test would indicate. Again, a selected sample would often show better in the test than the material from which it was taken would show under traffic in a road.

A careful examination of the gravel in a deposit will usually indicate, in a general way, whether or not it is durable enough for road purposes. If a large proportion of soft or partially disintegrated stones are encountered, the gravel should not be used unless it is very cheap, and contains a fair proportion of a good sand, and is to be used for what might be termed high-grade sand-clay construction.

Bonding Properties.—The bonding element in gravel is usually clay or loam, but may be of mineral composition such as iron oxide. The bonding qualities of some gravels are partly due to the angular shape of the particles and only partly to the clay. While the amount of clay in the gravel should not exceed about 15 per cent, a considerable range in clay content is found in gravels of good bonding properties. The kind of clay and the nature of the gravel with which it is mixed vary so much in the different deposits, that in many cases only service tests will reveal the behavior of the material under traffic.

Ideal Gravel.—The ideal gravel for the wearing surface of either the feather-edge or water-bound type is of such a range of sizes that 95 per cent will pass a laboratory sieve having circular openings 1 in. in diameter, and between 20 and 40 per cent be retained on a laboratory sieve having circular openings ½ in. in diameter. The portion below the ½ in. size should be reasonably well graded but should not contain to exceed 15 per cent of material passing the 100-mesh sieve. The pieces should be of sufficiently durable rock that when the material is tested by the modified abrasion test[1] the loss does not exceed 8 per cent. It is not to be expected that gravel otherwise acceptable will often

[1] The abrasion test for gravel is described in Chap. XXIII.

contain the desired amount or quality of binding material. That must be supplied in some way, generally by utilizing the subgrade soil as binder.

Grading.—The statement that gravel should be well graded means that the sieve analysis curve should show that the material contains no great excess of coarse or of fine particles, and that there is a reasonable amount of each size between coarse and fine. The reason this is desirable is that a mass of well-graded gravel will contain a smaller volume of air voids than one that is not well graded, and, consequently, requires less bonding material to hold the mass together. Also, well-graded gravels have greater mechanical stability than those in which the air voids constitute a large percentage of the mass. While it is desirable that road gravel be reasonably well graded, it is seldom possible to enforce rigid specifications as to grading, because local gravel deposits must be utilized almost exclusively. It is possible to vary to some extent the relative proportion of coarse and fine material in the gravel, and the maximum size, by appropriate methods of crushing and screening.

Selection of Gravel.—Knowing the desirable characteristics of an ideal gravel to be used for road purposes, the one nearest the ideal may be chosen from among those available, or two gravels may be mixed on the work, and thus a material produced which will be superior to either alone. It often happens that gravel roads must be built from local material which is far from ideal, but such gravel can be made into a serviceable road by careful manipulation.

The pit gravels fall into four groups: those that approximate fairly closely the ideal gravel; those that are too coarse; those that are too fine; and those that are deficient in bonding material.

If the gravel is too coarse, the larger pieces may be screened out and thrown aside, or crushed and mixed with the finer material. It may be desirable in some cases to add sand to increase the amount of fine material and to facilitate compacting the gravel in the road.

When gravel is encountered that is too fine, usually no coarse material is available to mix with it. Such a gravel can be used, if sufficient clay is present, or is added, to bond the gravel, and the road thus constructed will be much like the sand-clay road in character. It will be dusty in dry weather and somewhat

sticky on the surface in wet weather, but will usually be a fairly satisfactory road for moderate traffic.

The gravels which are deficient in bonding material are usually found in stream beds, or have been deposited by stream action on bars, but some bank gravels are also of this class. The deficiency in bonding material can be supplied by mixing clay with the gravel after it has been spread on the road. If this is carefully done, excellent roads result, because gravels of this class are usually very durable. Limestone screenings are an excellent binder for gravels of this character, particularly if a little clay is also added.

Preparation of Roadbed.—For local roads, by which is meant those carrying an average of not to exceed 100 vehicles per day, the preparation of the roadbed need not be elaborate. The necessary drainage ditches are constructed and the grades are reduced to the desired extent. As a rule, little grade reduction is justifiable on this type of highway beyond that needed to reach the economical maximum plus grade. The profile usually follows the minor undulations of the land and a width of about 20 ft. is graded to a level cross-section to receive the gravel.

For the more important highways the right-of-way is graded in accordance with the adopted design, which usually involves considerable grade reduction and some widening of the existing traveled way. The portion to be covered with gravel is generally finished with a level cross-section, and should be allowed to become fairly compact before the gravel is placed. A few weeks of travel accompanied by continuous maintenance will generally suffice, although 6 months of travel would undoubtedly produce a more stable foundation. In arid or semi-arid regions, there is nothing to be gained by delaying the placing of the gravel after the earthwork is completed.

If the trench method is to be followed, the earth is excavated to form a trench for the gravel, the excavated material being drawn to the sides of the road to form shoulders to retain the gravel. This method is followed where the water-bound gravel road is constructed, and is recommended if the gravel is coarse and does not contain an excess of fine material.

If the feather-edge method of placing the gravel is adopted, no special preparation of the roadbed is needed if the earthwork has been completed in the proper manner. The gravel is placed on the roadbed and feathers out at the edge, there being no earth

shoulder to retain it. Sometimes a small amount of earth is drawn to the edge of the gravel to keep it from spreading out unduly, but generally even this is omitted.

Width and Thickness of Gravel.—Single-track gravel roads are about 10 ft. wide and from 5 to 8 in. thick. Double-track gravel roads are about 20 ft. wide and from 6 to 10 in. thick at the middle and 5 in. thick at the edge.

On well-drained soils a 6-in. layer of gravel is adequate for automobile traffic and the light trucks. If trucks of two or more tons capacity use the road regularly, the thickness should be 8 or 10 in. A great deal depends upon the nature of the supporting soil, and the amount of rainfall to be expected. In the regions of light rainfall 5 in. of compacted gravel is sufficient for most rural highways.

Cross-slope.—On account of the tendency for the finer material in a gravel surface to loosen under traffic and gradually be pushed to the side of the traveled way, it is desirable to construct the surface with but little cross-slope. The prevailing practice in recent years has been to use a cross-slope of about ½ in. per foot of width. The surface is usually kept under patrol maintenance, which insures the loose material being replaced at frequent intervals, and under that condition a low cross-slope is permissible.

Placing the Gravel by the Trench Method.—The trench method is employed for gravels in which there is little excess fine material. A trench is prepared of the proper width and depth, and the gravel placed therein, usually in two layers of about equal thickness.

The gravel for the first spreading is dumped on the prepared roadbed in a quantity sufficient to give the desired thickness, and is spread with shovels and rakes, or more commonly, with a blade grader. With gravels of this type it is usually advantageous to stir the mass with a heavy stiff-toothed harrow after spreading, so as to distribute the finer material and reduce the layer to a relatively homogeneous mass. After the harrowing, the layer is finally smoothed with a blade grader. It may then be rolled, or it may be opened for traffic until partially compacted. If the material contains enough binder of the proper kind (clay and fine stone dust) it may be consolidated by sprinkling and rolling, but with many types of gravel the rolling has no beneficial effect.

The upper layer is placed and consolidated in the same manner as the lower. Sprinkling and rolling constitute the desirable method of bonding gravels of this type, and great care should be exercised to select materials of the right mixture to be successfully handled by this method.

In some instances, bonding material is provided by spreading a layer of clay on top of the lower layer of gravel. The upper layer of gravel is then placed and harrowed. This is followed by sprinkling and rolling to bring the clay up into the upper course and bond it together.

A comparatively small portion of the gravel roads are constructed by the trench method, and of those so constructed relatively few are finished by rolling and bonding with water. Most of them are opened to traffic and undergo slow consolidation as clay works into the gravel from the subgrade and shoulders.

Feather-edge Method of Placing Gravel.—For this method the roadbed is finished to a level cross-section, and the gravel placed thereon in a quantity that will form a layer about 6 in. thick at the middle and about 20 ft. wide. As first spread the layer will be about 3 in. thick at the edge but it will quickly spread until the gravel merges with the shoulder material. The gravel is spread with a blade grader and opened for traffic. Under the traffic, the material gradually becomes mixed with the roadbed soil, and bonds into a fairly compact layer. During this period frequent smoothing is necessary to insure a surface of the desired uniformity.

Another method is to place the required quantity of gravel in a ridge along the edge of the roadbed and then to spread it with a blade grader a little at a time. After each rain a layer of about 2 in. of gravel is spread over the road. It quickly mixes with the roadbed soil and is thus bonded together into what is in reality a high-class sand-clay surface. This method occasions a minimum of inconvenience to traffic, and is strongly recommended for gravels containing an excess of sand and very little material larger than the ½-in. size.

Placing Gravel on Sandy Soil.—In many places the roadbed consists of sand or very sandy loam, neither of which have any bonding properties. If the gravel is placed directly on such materials it will not compact unless the gravel contains about 20 per cent of clay, and even then enough sand is likely to work into

the gravel from the roadbed to interfere seriously with the consolidation of the surface. It is better practice to cover the roadbed with enough clay to form a layer 6 or 8 in. thick after it has become compacted. The gravel is then placed on top of the clay, usually by the feather-edge method.

Washed Gravel.—If very clean gravel, such as is obtained by dredging or pumping from river bars is used, it is necessary to add clay to bond the road surface. After the gravel has been spread on the road it is covered with about 2 in. of clay or loam from alongside the road. Most of this clay will shake down

FIG. 52.—A well-built gravel road.

among the pebbles as the traffic uses the surface, and the road will get out of shape easily. But frequent dragging will restore the shape as fast as it is destroyed by traffic, and the road will gradually become solid. A little additional clay may be necessary from time to time during the first 6 months at least on portions of the road. If the surface is reshaped daily and, after about a month of traffic, is covered with about 1 in. of good bonding limestone screenings, the next rain will cement the surface together into an exceedingly durable road.

A light blade grader is very useful for maintaining the surface during this period, and if the dragging is done carefully after the rains, a smooth, even, durable surface will result and a com-

paratively small amount of maintenance work will keep it in good condition.

Maintenance.—The maintenance of a gravel road begins immediately after it is opened to traffic, and is a continuous operation thereafter. The best maintenance work is done with the light blade grader which is used to smooth the surface and fill the ruts and depressions as they form. Usually the road must be smoothed daily if the traffic is 500 vehicles or more per day. For lighter traffic the frequency of the reshaping may be somewhat less, but is seldom adequate unless accomplished once a week. In dry weather the loose material that is spread over the surface by the grader is a protection to the body of the road and retards the raveling that normally results from motor traffic. Calcium chloride applied in flake or granular form at the rate of about 5 lb. per square yard will retard the raveling of the surface. New gravel must be added from time to time as need arises, and this material is added in small quantities (about 500 cu. yd. per mile) and spread over the surface. Preferably the work should be done in wet weather.

In recent years considerable success has attended the use of light tars and oils to bind the surface particles together, thus preserving the surface and eliminating dust. The exact method employed will be discussed in another place.

Cost of Gravel Roads.—Gravel roads of the feather-edge type range in cost from $1,000 to $4,000 per mile for surfaces 24 ft. wide, and the trench type costs from $2,000 to $7,500 per mile for surfaces 20 ft. wide. The maintenance costs from $200 per mile per year to $2,000 per mile per year, varying with the climate, the traffic, and the cost of gravel for resurfacing.

Sand-coated Roads.—In some sections of the United States there is found a black silty clay soil that bears up well under heavy loads but is very sticky in wet weather. If the surface is coated with just enough gravel to prevent the soil becoming sticky, a considerable improvement in the surface results. The usual procedure is to smooth the earth road and work the crown down to not more than ½ in. per foot of width. The surfacing material is applied exactly as in the construction of the feather-edge type of gravel road, but the quantity of surfacing material is held to the minimum that will eliminate the stickiness of the soil. No attempt is made to build up a layer of bonded gravel on top of the road. The quantity of surfacing material required

ranges from 500 to 650 cu. yd. per mile for a two-lane surface. In the course of 3 or 4 months the surfacing material becomes blended with the road soil, forming a sort of light sand-clay type of wearing surface. The gravel dressing will need to be repeated in smaller quantities at intervals of from 2 to 5 years, depending upon the soil, rainfall and traffic. A road of this type will soften in wet weather but dries quickly, and for light traffic is a distinct improvement over the untreated soil. It is not an acceptable substitute for the feather-edge gravel. The cost is generally from $350 to $600 per mile.

Characteristics of Gravel Roads.—Since the surfaces that are popularly known as gravel roads vary from those composed of a light dressing of coarse sand on top of an ordinary earth road, to substantial water-bound gravel roads of considerable thickness, a corresponding variation is to be expected in the serviceability of the gravel road.

The sand-coated earth roads are in reality traffic-mixed sand-loam or sand-clay roads, and the principal benefit of the surfacing is to reduce the stickiness of the soil when it is wet, and to hasten the drying after wet periods. Surfaces of this kind are not expected to constitute traffic-carrying crusts over the soil but rather to mix with the soil and add somewhat to its stability under light rainfall. These surfaces do not corrugate under traffic nor do they usually become very dusty.

Gravel surfaces that are of sufficient thickness to really constitute crusts over the earth foundation serve admirably for traffic up to 300 or 400 vehicles per day, and the more carefully constructed gravel roads will carry traffic up to 1,000 vehicles per day if the maintenance is continuous. The economical traffic capacity is probably in the neighborhood of 500 vehicles per day. If animal-drawn traffic prevails, a well-built gravel surface will carry any volume of traffic that can be put over it.

The gravel road tends to be very dusty in dry weather, and to become badly corrugated if motor vehicle traffic predominates. No amount of maintenance can eliminate these objectionable characteristics unless bituminous treatments are applied.

Most of the feather-edge gravel road surfaces soften somewhat in prolonged wet weather and at those seasons of the year when there is alternate freezing and thawing. At such times the supporting power of the gravel crust is low, and serious damage

is done to the surface by the heavier vehicles such as trucks and busses.

Problems

1. Write a specification for gravel to be used for water-bound gravel road construction.
2. Write a specification for gravel to be used for a gravel road of the feather-edge type.
3. Draw a cross-section for a two-lane gravel road to be constructed by the trench method, and estimate the quantity of gravel required for 100 ft. of surface.

EXAMPLE OF GOOD PRACTICE

Crushed Stone and Gravel Surfacing[1]

The subgrade on which the surfacing materials are to be placed should be given such preparation as is necessary to provide a well-drained stable foundation. Consideration should be given the soil, practical drainage where necessary, and the climate, before the selection of the materials to form the surface metal is made, and before the width and thickness of surface is determined.

After the value of the subgrade as a foundation has been studied, and the present and probable future traffic that the surface will carry is analyzed, the metal, either gravel, crushed gravel or crushed rock, may be selected. Such selection is a matter of economics with the criterion that the material selected shall give the service required at the least cost. Going hand in hand with the selection of the metal is the matter of the design of the cross-section.

Design of Cross-section

A surface 12 ft. wide and 6 in. thick is often all that is necessary for light traffic. However, there is and will no doubt be for some time, a very large mileage of unpaved highway that is subjected to traffic in an amount sufficient to justify paving. In selecting a design or surfacing for this traffic, as well as for a volume of traffic for which metal surfacing is suited, a cross-section following more closely to pavement design is recommended. The metal should be placed for a width of not less

[1] Hoover, J. W., *Canadian Engineer*, Sept. 27, 1927, Vol. 53, p. 327. (Somewhat condensed.)

than 18 ft. and should have a thickness at the edge of from 9 to 10 in. and a thickness across the center of from 7 to 8 in. Where the subgrade is unstable additional thickness of metal should be provided. A design similar to the above is of more importance where the more expensive water-bound macadams and dust prevention methods through oiling or other surface treatments are contemplated or probable in the near future.

Size of Surfacing Material

The maximum size of gravel or crushed rock was first rather large, often running as high as 3 in. As maintenance methods became more extensive the size was cut down until the extreme of 1½ in. for the base course and ¾ in. for the top course became common, with occasional specifications limiting the base rock to a maximum of 1 in. and the top course to ¾ in.

Practically all of these roads were maintained by frequent dragging and the ideal was expressed as a smooth compact base covered with from ½ to 1 in. of loose material to be worked back and forth across the road by means of the drag or grader. Highway surface construction passed through the coarse rock stage and there is now a large mileage of fine rock surfacing that may be treated to give a surface free from dust.

There is now developing a tendency to change to coarser rock or gravel in surface treatments to secure a smooth, compact surface, free from loose material particularly where the travel is heavy and where dust prevention is desirable.

Selection of gravel, crushed gravel, or crushed rock as a surfacing material has been based largely on the cost of the material on the road. This has resulted in natural gravel surfaces or crushed gravel surfaces in the glaciated areas and crushed rock surfaces in the unglaciated areas. Crushed rock has, in general, given the best service with crushed gravel and pit-run screened gravel, in the order named. There are exceptions as some deposits of natural occurring fine gravel can be worked into roadways comparable in every way with the best crushed rock.

The question of hardness of gravel or rock for surfacing has been given a great deal of study and, in general, the limits set forth in the specifications of the various states no doubt produce good results. It is not practical to use the same specifications in all of the states for the reason that the specification must be

fitted to the materials available, the soil, traffic and climatic conditions. Very often material is found that would not pass the specified tests, nevertheless it makes the best of road surfacing under the circumstances. The policy of the State of Washington is to test the materials available before the contract is advertised. The bidders are then advised by the special specifications as to the requirements for each grade of material. In this way the contractor is fully advised before making his bid as to the sources of gravel or rock, the element of gamble is materially reduced, and the state receives a better bid for the work.

Distribution of Surfacing Material

The surfacing material shall be uniformly distributed on the subgrade. If the inspector should be lax in this requirement the surfacing, when completed, will not be smooth and traffic will work depressions at the point where the material is not uniform and it will be some time after the work is completed before the maintanence forces can work up a first-class riding surface. The usual specifications also require that the contractor in so far as it is practical shall do his hauling over the surfacing as it is placed. In order to accomplish this the surfacing is started at the point of loading or the point of entrance on to the highway and worked away from that point.

It is also necessary to drag the surfacing material as much as is necessary to keep it smooth. Where the surfacing is to be constructed in two courses, the contractor is required to construct as much of the base course as is possible from any one set up of bunkers before beginning the construction of the top course. Where the entire product of the crusher is to be placed in the base course, it is required that the entire base course shall be constructed before starting in the top course, and where the product of the crusher is separated into sizes only the base shall be constructed until the section of the bunkers for the finer material is filled, at which time the top course may be started. In this way the hauling equipment is used to secure as much compacting of the two courses as is practical. By dragging the surfacing and keeping it smooth the trucks do not run in the same tracks and the traffic is distributed over a wider area.

Very few specifications give sufficient attention to the binding material required to be added to the surfacing. The usual specifications permit the use of side of the road material or any

other material that is easily available and having some binding qualities. The binding material should be a water-resistant clay, which when mixed with the surfacing material will harden.

The State of Oregon has given this part of the work a great deal of thought and attention during the past few years and has secured very good results.

Keep Subgrade Smooth

Too much emphasis cannot be placed upon the necessity for keeping the subgrade smooth and each course of surfacing smooth during the entire operation of constructing the road, and afterwards by means of the maintenance organization. The best results are obtained in this type of surfacing by constructing in at least two courses; the base course containing rock having a maximum size of 1½ in. and the top course composed of rock which will pass a ¾-in. ring. The two courses should be of equal thickness which should be for each not less than 3 in. The thickness of the surfacing depends upon the character of the subgrade, the traffic, and the climatic conditions. In some regions such as the arid regions of Washington, where the rainfall is only from 6 to 10 in. per year, light surfacing holds up very well. In other localities a very heavy course of surfacing is nesessary by reason of a rainfall that is more than 100 in. per year and a subgrade that becomes very soft when wet. The best results in the heavy rainfall area are obtained by using the product of the crusher in the base course as this builds up into a crust with comparatively little binder due to the interlocking effect of the crushed material. In the arid regions the product of the crusher may be separated into the two sizes and the base course bound up with good clay and the top course placed and bound up with clay. A great variety of specifications for the size of material in each course is possible, depending upon the materials that are available to provide the facilities for traffic at the least cost.

The available materials should be given thorough study for each project. Of course in some localities there is no choice. Surfacing constructed in more than two courses is oftentimes advisable due to a soft subgrade that cannot be cared for by drainage or by raising the grade line without excessive cost; in some instances a base course of large rock is advisable and economical.

CHAPTER X

WATER-BOUND MACADAM ROADS AND PAVEMENTS

A type of road surface consisting of broken stone cemented into a solid mass by means of stone dust and water, is known as water-bound macadam. The surface thus constructed depends for its stability upon the somewhat weak cementing property that is possessed by the dust from the rock used for the surface layer. The water-bound macadam surface that is made with good stone on a good subgrade will be sufficiently stable to carry loads of considerable weight, but the integrity of the surface depends upon the excellence of the cementing properties of the stone dust used. The water-bound macadam has little place in a modern road system to be used by self-propelled vehicles, as it will not hold together under any considerable volume of that kind of traffic. It is still constructed as the first stage in the building of surface-treated macadam, or as a base course for penetration or mixed macadam. Typical cross-sections for macadam are shown in Fig. 53.

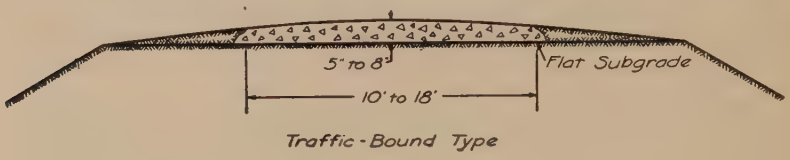
Materials.—Limestone, granite, and the various kinds of rocks designated as trap, are the principal water-bound macadam materials, limestone and trap being employed much more extensively than the other kinds.

Slag, shells, burnt shale, low-grade iron ore and sandstone are occasionally utilized, but cannot be considered of wide importance as macadam materials although satisfactory for local roads in some regions.

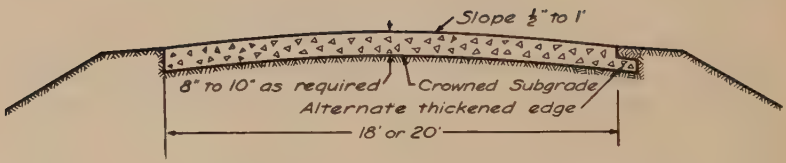
Quality of Rock.—A macadam road is subjected to the constant abrasion of the tires of vehicles which tends to grind off particles from the surface stones. In order to resist this action the stone must possess the quality of *hardness.*

The surface is also subjected to constant pounding from heavy loads, which tends to chip off fragments from the rocks or to break the rocks into smaller pieces. The quality of the rock that enables it to resist destruction in this manner is known as *toughness.* The toughness, as determined by standard tests, should not be less than 6.

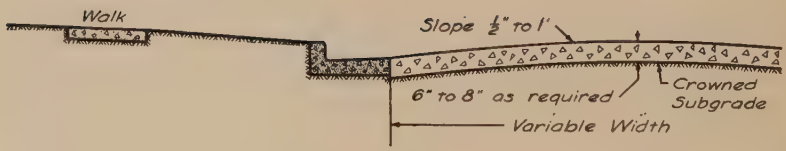
The individual pieces of stone in the surface of the road are constantly being moved slightly in the mass, due to distortion of the surface under heavy loads. This causes the pieces of stone to rub and grind against each other, and to resist this



Traffic-Bound Type



Rolled and Waterbound Type



Light Traffic Street Pavement

FIG. 53.—Typical cross-sections for macadam.

effect the stone must have good *wearing properties.* The abrasion test which determines the wearing property is also to a degree a measure of the ability of the stone to resist the grinding action of traffic and shock, so that the test is really a combined hardness

and toughness test. The percentage of wear as determined by the Deval test should not be more than 8.

The individual pieces that make up the surface of the road are held in place partly by the mechanical interlocking induced by the rolling and partly by the cementing action of the stone dust or screenings that fills the interstices between the larger stones. It is therefore exceedingly important that the stone have good *cementing properties.* The cementing value as determined by the standard test should not be less than 100.

Since the surface stones are held in place by the cementing action of the screenings and since these screenings will blow away, will be whipped off the surface and out of the spaces between the stones by automobiles, and will be washed away by storms, it is necessary for this bonding material to be replaced from some source. As the stone wears away the dust thus made will serve to replace that which is removed, and therefore the surface will remain in better condition under mixed traffic if the stone wears fast enough to furnish the right amount of dust. Just what grade is best for any particular road will depend upon the traffic.

Size of Stone in Surface Layer.—The maximum size of stone is that size which is just strong enough to carry the loads on the road without crushing. A tough stone need not, therefore, be as large as one low in this property. The size is further limited, however, when in order to secure a stone large enough to withstand traffic, a size is reached where the stone will tip in the surface as a wheel rolls over it. While some engineers permit the use of a stone passing a 3½-in. ring, it is probable that a size passing a 2½-in. ring is about the largest that can be recommended. If the stone is high in the property of toughness, the size need not be so great.

As a general principle it may be said that if the French coefficient of wear exceeds 12, the size for the surface layer may be from 2½ in. down to ¼ in. and the size from ¼ in. down may be utilized as screenings for bonding the surface. If the stone has a coefficient of wear less than 12, the size may be from 3½ in. down to about ½ in. and the screenings may be from ½ in. down.

Size of Stone for Lower Course.—It is not so important to have the stone for the lower course of any particular size so long as it is convenient to place and roll. Good serviceable roads have been built with the lower course made from screenings ½ in. down, but this cannot be recommended as good practice. Any

size obtainable up to that which passes a 4½-in. ring will serve. The lower course is generally made of a stone larger in size than that which composes the upper course because of the economy in cost of crushing. Not infrequently, however, the same size of stone is used for upper and lower courses.

Size of Stone for Telford Foundation.—The requirements as to the permissible size of stone for Telford foundation are not very rigid. A size that can readily be handled by one man is suitable. One dimension ought to be within 1 in. of the specified thickness of the foundation which may be 6 to 8 in., the width as set is from 5 in. to 1 ft. and the length from 8 to 15 in. The essential requirement is that the pieces conveniently lay up to the required thickness of course. If too large, the stone will not lock together so as to be stable under rolling. The larger pieces are "chinked" with spalls so as to hold them firmly in place.

Crusher-run Stone.—Stone is sometimes taken directly from the crusher and placed on a road. Since the screenings are mixed with the stone, it may be compacted by rolling or by traffic and will bond into a fairly stable surface. Such a method of construction is suitable only for light-traffic roads, and the surface is not likely to wear evenly. Since rubber tires do not constitute a very good roller, it is best to compact the stone with the macadam roller.

CONSTRUCTION OF THE SURFACE

It will readily be seen that a macadam surface cannot distribute the load it carries over a very great area of subgrade because the layer of bonded stone does not possess flexural strength. It is commonly assumed that the load is carried to the foundation on 45 deg. lines from the area of application of the wheel or other load. Whether or not this is true, it has been shown by many examples that any ordinary soil, when well drained, will carry wheel leads up to 2 tons if the macadam is made 8 in. thick.

Exceptions must be made to those soils that are of seepy or peaty nature and are impossible of complete drainage. Here the Telford type of foundation would be used.

The roadbed is prepared by constructing the necessary side ditches and placing suitable under-drainage, as in building a good earth road. The results will be more certain if such work

could be done some months prior to the placing of the macadam, as is recommended for gravel roads.

Thickness of Macadam.—The thickness of the completed macadam road is variously specified in regions where this type is still built, but will generally lie between 8 and 10 in. if the roadbed soil is reasonably stable. It appears that the 8-in. thickness predominates. If the foundation is of gravel, deep sand or other equally stable material, the thickness may be as little as 6 in. It is not probable that a macadam surface will prove to be economical, if a thickness greater than 12 in. is necessary for stability. The thickness mentioned is in each

FIG. 54.—A poorly constructed macadam which is raveling.

case that which is obtained after thorough rolling which is about 80 per cent of the thickness of the loose material.

A roller will not compress properly more than about 6 in. of loose stone; therefore it is common practice to place the material in two approximately equal layers, rolling the lower course thoroughly before the upper is spread.

When the Telford type of foundation course is employed, its thickness is usually about 6 in. but may be as great as 8 in. The Telford base is carefully placed by hand and all chinks between the stone filled with spalls, gravel, or crushed stone and then rolled with a 15-ton roller.

The upper layer for a Telford macadam is about 3 in. thick after it has been rolled.

Quantity of Stone Required.—A macadam surface 8 in. thick, after rolling, requires 27 cu. yd. of stone per 100 ft. of road 9 ft. wide, to which must be added 3 cu. yd. of screening if the upper course only is bonded, and 5 cu. yd. if both courses are bonded. Pavements of other widths and thicknesses may be computed on a basis of a shrinkage of 20 per cent in the layer of stone during rolling. The quantity of screenings required to bond a layer of stone is 20 per cent of the volume of the layer. These quantities hold true for most materials within the limits required for estimates, but will inevitably vary slightly with the size of stone, fineness of screenings, and actual density of the layer after rolling.

Roadbed and Shoulders.—It is imperative that the broken stone be placed between substantial berms or shoulders of earth so that when rolled it will be compacted, not merely spread out. The earth shoulders may be formed by removing the earth from the middle of the road for the required width and grading it out to the sides, thus forming a trench for the stone, and this method is followed when the road to be surfaced is already well shaped up and has the requisite cross-slope.

If the road to be improved lacks the cross-slope or crown necessary for good drainage the shoulders are formed by drawing material from the sides of the road and the ditches. The shoulders thus obtained will be loose and will require thorough rolling prior to placing the stone to insure that they will not spread out when the stone is rolled.

It not infrequently happens that both methods of forming shoulders will be necessary on adjacent sections of a road, on account of the lack of uniformity of the existing earth-road section.

The surface upon which the stone is placed is referred to as the subgrade, and usually is made with a convex cross-section. This is desirable for any kind of hard surface that is sufficiently porous so that there is a possibility that some water may soak through to the subgrade. When the subgrade is crowned the water will work to the edge and soak away into the shoulder or be conducted away through broken-stone drains.

The subgrade must be shaped with care so that no uneven places exist because these will either reduce or increase the thickness of the macadam depending upon whether they are above or below grade.

Since the stability of the surface depends to a large measure upon the solidity of the subgrade, it is rolled thoroughly. If soft and yielding places are encountered the soft material is removed and good material substituted, or, if ground water is encountered, the necessary under-drainage is put in to remove the water and permit the proper compacting of the earth.

Placing the Stone.—If the Telford base is employed, it is placed and rolled as previously described.

When the lower course is of broken stone and is spread by hand, the loads of stone are dumped in such a manner as to be convenient for spreading and the stone then spread by means of ballast rakes.

The thickness is gaged by means of cubes of wood of a size equal to the thickness of the course of stone. These are placed before the load is dumped, and the material is raked down until even with the tops of the blocks. They are then taken out and placed in position for the next load. This method is impractical if the material cannot be spread as rapidly as it is hauled.

The thickness is sometimes gaged by means of iron pins set with the top at the proper height to indicate the thickness, but otherwise the method is identical with the one in which the blocks are employed.

When stone is hauled in wagons or trucks that are constructed so as partially to spread the material as dumped, the driver attempts to move at such a rate as to spread the stone about to the proper thickness but the layer must be finally trimmed up by means of rakes. The trucks used for hauling stone are usually equipped in this way and spread the material quite satisfactorily.

The blade grader is frequently employed for spreading the stone. The loads of stone are dumped at such a distance apart that when spread they will cover the surface to the proper thickness. After a number of loads have been dumped they are spread by means of the grader. Usually a little hand work with the rakes is necessary to take out uneven places.

When the loads of stone are dumped, the finer material, of which there is always a certain amount in the load, will be deposited in the center of the pile while the coarse will roll to the edges. After the stone is spread the finer material will be in the middle portion of each space covered by one load of stone. This has a tendency to cause unevenness during rolling

FIG. 55.—Macadam surfaces under construction.

and is obviated by thorough harrowing, which mixes the finer material with the coarse or causes it to drop to the bottom of the layer.

No matter what system of spreading is employed, it will be found advisable to go over the stone with a blade grader just before rolling, to finally smooth the surface. Only a very small amount of stone willl be carried along by the grader and this will fill the low places that exist and the blade will drag down the high places.

When stone is being spread in a layer less than about 4 in. thick, the spreading must be done by rakes to insure the proper degree of accuracy, and this is particularly true of the upper layer of a road that is to be finished as penetration bituminous macadam. In spreading these thin layers, a templet is used as a guide to the thickness, the ends of the templet being supported on side forms set to the proper grade.

Blind Drains.—If there is rain during the construction period the water will percolate through the layer of stone and collect in the subgrade, particularly along the shoulders. To protect against damages at this time, blind drains, which are merely trenches sufficiently deep to permit the water to run freely from the subgrade, are dug and partially filled with coarse broken stone which is covered with earth to the level of the shoulder. The stone is generally put in them as the lower course is deposited. These drains are spaced about 50 ft. apart on each side of the road but may be closer together in the low places in the road and be omitted near the hilltops. On long hills it is desirable to excavate every third pair of the lateral drains to a depth of about 5 in. below the subgrade and extend them to meet at the middle of the road. The drains are sloped slightly downhill on grades and are at right angles to the center line elsewhere.

Rolling.—For limestones a roller weighing about 400 lb. per inch of width of roll is used, and for trap and similar stones, one weighing about 600 lb. per inch of width is employed. On the lower course the rolling begins at the edge of the stone and the roller moves parallel to the edge of the stone and at a speed of about 100 ft. per minute. The machine moves backward and forward, edging in toward the middle at each trip and when the middle is reached the roller is taken to the opposite side of the road and the process repeated. The roller then returns

FIG. 56.—Some types of macadam and tandem rollers.

to the side first rolled and this is repeated until the stone is thoroughly compacted. A roller will properly compact and bond about 50 sq. yd. of road surface per hour.

When rolling is completed each piece of stone will be wedged tightly between its fellows and will thus be restrained against any lateral displacement. At this stage of the rolling it will be noted that the stones have begun to break under the roller. If the rolling is continued the stone will crush and wear against each other and begin to loosen in the surface.

Rolling the upper course of the macadam road is carried out in the same manner as on the lower course except that the rolling begins out on the shoulder about 4 ft. To do this successfully the shoulders must be trimmed to such a height that they will roll down level with the stone.

During the rolling some uneven places will appear, and these are brought up by the addition of a small quantity of stone of the same size as is used in the course. A skillful roller operator will frequently sight along the surface of the macadam to detect uneven places and will manipulate the roller to produce a smooth, uniform, tightly keyed surface. Much depends upon the skill and experience of the roller operator and thorough rolling is a vital part of the construction of macadam roads.

Applying Screenings.—After the rolling on the upper course is completed no vehicles are permitted to use it until the screenings have been applied. These are dumped in piles at the side of the macadam and are thrown onto the surface with a sweeping motion of the shovel so that they will not be deposited in piles. The quantity used is that which will just cover the stones. Frequently, the screenings are brushed into the surface with fiber brooms. Some engineers then sprinkle the surface lightly and others roll the screenings dry. As the rolling proceeds bare places will appear and screenings are added until the layer is filled and a small quantity remains on the surface.

Puddling.—When the required quantity of screenings has been rolled into the layer of stone, the surface is sprinkled and rolled, the roller following immediately behind the sprinkler so that the spray of water falls on or just ahead of the roller. As successive trips are made with the roller the dust and the water form a mortar which is worked into every crevice in the surface. This operation of *puddling* is exceedingly important if a durable surface is to be constructed.

When puddling is completed the road is closed to all traffic until the screenings set up, which may be for 2 days or a week, depending upon the weather. If it is very hot and dry it is well to sprinkle daily for 2 or 3 days.

After the screenings have set the surface may be rolled again after each rain and the more rolling it gets at such times the better.

Finishing the Shoulders.—The shoulders should be neatly trimmed to the proper cross-slope, the back slopes to the ditches and the side slopes on cuts and fills be trimmed, and the ditches be properly shaped and cleaned of all loose earth.

Maintenance.—The surface may suffer almost entirely from one of the following causes or it may be subjected to all of them

FIG. 57.—A macadam road in need of surfacing.

simultaneously. The method of maintenance will depend upon just how the surface wears.

If motor traffic predominates, loss of binder will result, and in order to maintain the surface under such conditions, it will be necessary to renew the binder as fast as it is swept off. Screening or bonding gravel may be used for this purpose, and where possible should be put on while the road is wet. If the volume of motor traffic is in excess of 200 vehicles per day, bituminous treatments are required for satisfactory maintenance.

If the surface wears rapidly, new material must be added from time to time to maintain the thickness. Chuck holes and ruts will appear and these must be filled to maintain the smooth surface.

When new stone is added, the old surface must be loosened to insure that the new surface will unite with the old. Where

the area to be patched is small the loosening is done by hand with picks, but when extensive resurfacing is necessary, the scarifier or spikes in the roller wheel can be most economically employed. The surface is loosened to a depth of about 4 in., the new material is added and rolled or tamped in place. Screenings are then spread and the patches of new surface bonded, just as in the construction of a new road.

It is important to keep a broken-stone road in a smooth condition because if a chuck hole starts or a rut appears, it will rapidly increase in size, and the comfort and convenience of traffic will be interfered with.

No matter how faithfully a water-bound macadam road is maintained, it will be inadequate to meet the demands of motor traffic unless treated with a bituminous binder to keep the surface intact.

Costs.—The cost of light traffic-bound macadam surfaces ranges between $3,000 and $7,000 per mile 18 ft. wide. The rolled and water-bound macadams range in cost between $6,000 and $15,000 per mile for surfaces 20 ft. wide. The cost of maintenance averages about $750 per mile per year exclusive of bituminous treatments.

TOOLS AND MACHINERY USED FOR GRAVEL AND MACADAM CONSTRUCTION

Earth-working Tools.—The earth-work incident to hard surfacing is performed with the tools and machinery that have already been described in the chapter on earth-road construction. In addition, many other types of machinery are needed.

Stone Forks.—For unloading coarse crushed stone from cars or loading it from storage piles the stone fork is preferable to shovels. The forks are of various sizes, but one about 14 in. wide with tynes 1 in. apart is suitable.

Stone Rakes.—A rake of some sort is needed for spreading crushed stone in macadam construction. The type known as the ballast rake has tynes about 6 in. long and five or six in number. It is best to fasten two rakes together "back to back" so as to make a "two-man rake." Two men who become accustomed to this form of rake can handle a large amount of stone with ease.

Narrow-gage Dump Cars for Hauling.—When the haul for materials exceeds 2 mi., and the amount of material to be hauled is 10,000 cu. yd. or more, a narrow-gage industrial railway is

economical, unless the grades exceed 2 per cent. These outfits are made with sectional portable track which can be placed quickly and cheaply and can readily be shipped. The cars have a capacity of 1½ or 2 cu. yd. and are arranged to dump sidewise. About six of these can be drawn by a team or from 20 to 30 by a dinky locomotive. The initial cost of the equipment precludes its use except on large work.

Motor Trucks.—The motor truck for hauling road materials has almost entirely superseded all other methods of hauling road materials, particularly where the hauling is over reasonably good roads or for delivery over pavements.

Motor trucks are made with capacities up to 5 cu. yd. and motor trucks of the trailer type are of even greater capacity.

FIG. 58.—Harrow suitable for macadam and gravel road construction.

These trucks are self-dumping, travel rapidly, and when used in connection with some quick-loading device will handle large quantities of materials.

Loading Devices for Materials.—If road materials are being used in small quantities some economy in team hauling can be effected by the loading chute. These chutes are built to be attached to the side of the car and the material is shoveled into them from the car. When an empty wagon arrives, the contents of the chute is dumped into it by merely tripping the door. Thus there is no team time lost while the wagon is being loaded.

If large quantities of road materials are being handled and it is possible to secure railroad cars with dump bottoms, the loading can be done more economically with a bucket elevator. The hopper is constructed under the track and the boot of the elevator placed so that when the car is dumped the contents are fed into the elevator. An outfit of this kind can be installed

that will readily load 1 cu. yd. of stone per minute. In order to obviate the delay while the railroad cars are being shifted, a hopper is sometimes built into which the elevator deposits the material. From the hopper the material is let into the wagons through chutes. The cost of loading materials from cars to wagons with this equipment is not much less than for shoveling it by hand, but the loading is much expedited and the necessity for a large force of laborers done away with.

The locomotive crane with clam-shell bucket used in connection with the storage bin is also well adapted for loading materials on large work.

Self-propelled Rollers.—Steam-and gasoline-driven rollers are quite general in macadam road construction and in various kinds of pavement construction. Two types known, respectively as macadam rollers and tandem rollers are built. The macadam or three-wheeled roller is designed for compacting embankments, for rolling the foundation of roads and pavements, and for the construction of the various kinds of macadam roads. The weight may be from 8 to 20 tons but for all-around work the 10-ton size is most suitable. The width of the roller varies with the weight but the relative amount of weight on the front and rear rolls should be about the same for all sizes and since the rear roll is larger in diameter than the front, the weight on the rear roll should be about 0.6 of the total weight. The combined width of the two rear rolls should equal the width of the front roll and the path of the rear roll should overlap the path of the front roll about 4 in.

Scarifiers.—The scarifier is designed for loosening the surface of gravel or macadam roads when repairs are to be made. It consists of two or more hard-steel teeth set in a heavy frame so arranged that the depth to which the teeth penetrate the surface of the road can be adjusted. The scarifier is usually drawn by a tractor or roller and some types are built so that they can be steered independent of the tractor. Scarifier attachments are also provided for some of the heavier blade graders.

Portable Stone-crushing Plants.—For portable crushing outfits the jaw type of crusher is most commonly employed although the gyratory crusher is also made in small sizes. The crushing plant consists of the crusher which will have a capacity of about 10 cu. yd. per hour, and the screening equipment and storage bins. The cylindrical revolving screen is used and is

equipped with sections of screen to suit the work in hand. Storage bins are provided with sufficient capacity to take the output between loads so that the plant can run regardless of the regularity of hauling. For portable outfits the ordinary well-driller's rig is used for drilling the ledge for blasting out the stone.

Stationary Crushing Plants.—For the larger installations the gyratory type of crusher is employed and the other machinery and method of operation is much the same as for the smaller plants, except as regards size. The drilling is done by means of steam or air drills.

All stone crushers are built in such a way that the maximum size of the product can be adjusted, and the screen sections can be adjusted by removing the perforated metal and replacing with another size.

Problems

1. Write a specification for limestone to be used for a water-bound macadam that is to be used for the foundation course of an asphaltic concrete pavement.
2. Draw a cross-section for a two-lane water-bound macadam road with a Telford base and estimate the quantity of each kind of material required for 100 ft. of road.
3. Assume that you have received a letter from a county engineer inquiring how to resurface a badly rutted trap-rock water-bound macadam surface. Write an appropriate reply to the inquiry, assuming that he desires to restore it as a water-bound macadam.

EXAMPLES OF GOOD PRACTICE

A. Wisconsin[1]

Surfacing—Quantities Required

The following table gives the number of cubic yards of material per mile to make a given loose depth for various widths of roads:

[1] Wisconsin Highway Commission, *Bull.* 4.

TABLE X.—QUANTITY OF MATERIAL REQUIRED FOR MACADAM ROADS

Depth of loose material in inches	Width of surfacing				
	9 ft.	14 ft.	15 ft.	16 ft.	18 ft.
	Cu. yd.	Cu. yd.	Cu. yd.	Cu. yd.	Cu. yd.
1¼ in. (screenings)	180	280	300	325	367
3 in	440	684	733	782	880
4 in	587	913	979	1,043	1,174
5 in	734	1,141	1,222	1,304	1,468
6 in	880	1,369	1,466	1,565	1,760
Square yards of surface per mile	5,280	8,213	8,800	9,387	10,560

The following table gives the number of linear feet of 9-ft. road which a load of a given size should cover for various loose depths.

Foremen must compel spreaders to use this table.

TABLE XI.—SHOWING LINEAR FEET OF 9-FT. ROAD FOR VARIOUS SIZES OF LOAD

Weight of load		Loose depth in inches				
Granite, lb.	Limestone, lb.	Size of load, cu. yd.	3 in.	4 in.	5 in.	6 in.
2,800	2,500	1	12 ft.	9.0 ft.	7.2 ft.	6.0 ft.
3,500	3,125	1¼	15 ft.	11.25 ft.	9.0 ft.	7.5 ft.
4,200	3,750	1½	18 ft.	13.5 ft.	10.8 ft.	9.0 ft.
4,900	4,375	1¾	21 ft.	15.75 ft.	12.6 ft.	10.5 ft.
5,600	5,000	2	24 ft.	18.0 ft.	14.4 ft.	12.0 ft.
6,300	5,625	2¼	27 ft.	20.25 ft.	16.2 ft.	13.5 ft.
7,000	6,250	2½	30 ft.	22.5 ft.	18.0 ft.	15.0 ft.
7,700	6,875	2¾	33 ft.	24.75 ft.	19.8 ft.	16.5 ft.
8,400	7,500	3	36 ft.	27.0 ft.	21.6 ft.	18.0 ft.

Weights of Material

When buying by weight, to find the amount required, estimate that limestone weighs 2,500 lb. per cubic yard of 27 cu. ft.; granite, disintegrated granite and quartzite 2,800 lb.; unscreened gravel or sand 3,000 lb.; and crushed gravel 2,650 lb. Finer-crushed sizes will weigh more than coarse sizes. The above averages the three sizes commonly used if they are dry. Screenings, sand and gravel are often shipped wet and will weigh far in excess of the above.

Spreading

The simplest and most satisfactory way to spread stone accurately to a definite depth is to know how many cubic yards are in a load, and figure from the foregoing table how many feet of road it should cover to the depth required, and to spread it over that many feet and no more or no less. It is much the most convenient to have all loads hauled the same size, in which case the spreader can measure accurately just how to dump each load. To find the capacity in cubic yards of a wagon, multiply the inside length by the width and then by the height (all in feet) and divide by 27.

It takes a good man to make a good spreader. Much of the looks of the road depends upon his work and much of the money available can be wasted by a careless workman who puts on too much material. Check the loose depth of the stone often and see that he is spreading each load to the proper distances so that stone is neither too thick nor too thin.

First Course

(No. 1 stone usually 2 to 3½ in. in size, usually spread to a loose depth of 5 in., never more than 6 in. and seldom less than 4 in.)

The first course of rock or gravel can now be dumped on the subgrade and spread to the required thickness with rakes and shovels, after which it is to be rolled until it is packed firm and hard and there is no movement under foot as you walk on it. On very sandy soils, to keep the sand from working up through the stone, place a fair covering of clay, marsh hay, straw, or weeds (good in the order named) before placing any stone. Shoulder trenches should be filled with the No. 1 stone so as to

make blind drains. Cover the stone in the trench with sods, grass side down, or with hay or straw to keep dirt from clogging the water course. Care should be used in rolling the first course to keep the roller in the trench and not to overlap the stone and crush the shoulders. Roll from outer edge toward center. Clay or screenings are seldom necessary on the first course. Place about 200 ft. of first course stone before starting to lay No. 2. No. 1 bin does not usually hold this much, but No. 2 stone can be put in the bottom course until the first course is laid 200 ft. ahead, provided the two sizes are kept in separate strips, laying say the first 125 ft. of No. 1 and then starting with No. 2. Some prefer to pile the No. 2 until the No. 1 is far enough ahead and use it when the end of the work is reached.

Harrowing

Although not much used in Wisconsin, many highway engineers claim that a good spike-toothed harrow is a necessity in properly compacting stone and gravel, and that a large part of the rolling of the two first courses can be saved by thorough harrowing after spreading. The Commission will have this method thoroughly tried out on several jobs this summer, and hopes that some of the County Highway Commissioners will also experiment with such harrows.

Second Course

(No. 2 stone, usually ½ to 2 in. in size; usually spread to a loose depth of 4 in., never more than 5 in., seldom less than 3 in.)

The second course of stone is now hauled on top of the first and spread evenly to the depth called for. This course is rolled commencing on each outer edge with the rear wheel half on the stone and half on the shoulders and rolling toward the center. The roller should be run over this course a number of times until the stone or gravel is brought to shape and fairly well compacted before screenings or dust is applied. All low places that have shown up should be filled with No. 2 stone and high spots raked down so that the surface presents a smooth even appearance.

Third Course or Screenings

(No. 3 stone, usually from dust to ½ in. in size. Not necessary in pit-run gravel or shale roads.)

Screenings may be hauled at any time after subgrade has been finished. Dump in piles with inner edge about 2 ft. from edge of trench or subgrade. Never dump screenings on the second course. If 1 cu. yd. of 27 cu. ft. is dumped in one place, the centers of piles should be about 30 ft. apart for 9-ft. road or about 18 ft. apart for a 15-ft. road. A cubic yard of screenings under ordinary conditions will cover about 275 sq. ft. of surface. A cubic yard of screenings bought by weight is not a cubic yard by measure, especially if wet.

Use a square-point dirt shovel to apply screenings. Put them on very thinly with a quick sweeping motion, working from one end of the road toward the other. Keep roller running constantly while putting on the screenings. Repeat this process until all voids between stones are filled. Roll until stone stops moving and the surface is hard, and all second-course stone slightly covered with screenings. It is necessary to bind quartzite or granite with some good cementing material, such as clayey pea gravel or disintegrated granite. If neither of these are available, it is best to use a limestone top course or bind the granite with a bitumen. Clays and limestone screenings have not proven to be satisfactory binding materials for this class of stone. If clay is used, apply it dry a little at a time, and after the voids are well filled and the road is rolled, cover the surface with screenings, preferably with the dust screened out. Don't use too many screenings—just enough to cover the road nicely at all stages is just right. Too many screenings simply allow the road to rut more easily.

Flushing

With the stone covered with screenings the road is ready for water. On clay soils trim down shoulders with road machine before applying water to prevent too much mud at sides. Don't try to finish over 400 ft. of road at one time. It will dry out before you get it soaked. It is customary to finish up each night or every other night the road ready for finishing. If screenings stick to tires, scrape them off or keep tire well wet, or both. Sprinkle road until screenings are thoroughly soaked and tires run clean. When road is wet enough, follow sprinkler with roller. If screenings pick up on roller wheels, stop rolling and apply more water. Keep roller as close to sprinkler as possible. If bare spots or holes appear, put on enough dust to cover them.

Sprinkle and roll until water is continually carried along in front of the roller wheels at every point of the road being flushed. Road is then finished. Pit-run gravel roads are flushed in about the same way, but must be very wet when rolled or quite dry. A rainy day is the best time to finish a road.

If the road fails to compact and is spongy under the roller, the subgrade is too wet. Take the roller off and wait until the road dries out, or if conditions are very bad, dig out the stone and mud underneath, refill with good dry material and surface again. Use tile drain where necessary. Never have more than 600 ft. of unfinished road on your hands. Keep the work compact and finish as you go.

B. Sledged-stone Base Developed[1] for Missouri Roads

Sledged-stone base, with penetration macadam or asphaltic-concrete surface, has been adopted as a standard construction on Missouri highways. On the porous, easily-drained soils of large sections of the state these bases are standing up excellently and are being placed at an appreciable saving as compared with crushed stone or hand-placed Telford. Quarry rocks too soft to provide a crushed stone that will wear can be used as one-man stone for sledged base. Limestone has been used commonly but now sandstone is being tried where it is the native rock.

Rock is plentiful in most parts of Missouri, but there is little which has the coefficient of hardness required of crushed stone suitable for modern macadam. In large sizes—one-man stone—the softness is less objectionable than when the rock is crushed. Used as a base and filled with spalls, crushed stone and screenings, the large stone apparently breaks down very slowly due to internal movement of the fragments, but crushed bases of this rock grind up quickly. Hence the sledged-stone base has developed as a means of utilizing local rocks. Briefly it consists of large stone bound together and interlocked by sledging after which spalls, crushed stone, and screenings are filled into the interstices and rolled firm and smooth.

The sizes of stone used run about as follows: (1) As large as one man can readily handle, (2) spalls of any size up to 6 in.; (3) crushed stone passing a 3-in. ring, and (4) screenings which comprise all fragments passing a ¾-in. ring. The large stones are uniformly spread on a prepared subgrade. Then with 10 or

[1] *Eng. News-Record*, Aug. 23, 1923.

12-lb. sledges pound down the projecting tops and hammer the stone into contact and interlock. In sledging, the men work to secure as nearly uniform depth and as even a surface as possible. The surface is then rolled with a 10-ton roller to set and interlock the stone still further than did the sledging. Spalls and crushed stone are next spread to level the surface and then the base is rerolled. The screenings are used to fill in remaining hollows and the base is again rolled. On this sledged-stone base any type of surfacing can be laid.

In contracting for sledged-stone base the practice is to pay a unit price per cubic yard for ¼-mile haul. Measurement is made at the point of delivery and the price includes loading, unloading, sledging, rolling, etc.—complete base ready for surfacing.

USEFUL REFERENCES

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CHAPTER XI

ROAD SLABS OF CONCRETE

During recent years, increasing attention has been given to the nature and magnitude of the stresses to which road slabs of concrete are subjected by traffic and by climatic action. The gravel and macadam surfaces carry traffic loads by virtue of their capacity to distribute the load on the supporting soil to such an extent that the bearing power of the soil is not exceeded. When the traffic load is so great that it cannot be thus distributed the road crust deforms in order to maintain contact with the subgrade, but the movement of the crust may be accomplished without it actually rupturing. These road surfaces do not possess flexural strength and cannot therefore act as elastic beams or slabs.[1] The very lean concretes formerly employed in foundation courses for pavements were of much the same character.

The new conception of the concrete road slab, whether it be used as a foundation course or a combined foundation and wearing course, is that it has the properties of an elastic solid and hence its stability under load is directly related to its flexural strength. The use of slabs of this type introduces new problems of design, involving considerations of load, temperature and moisture effects on the concrete, and the influence of subgrade support on the stability of the overlying slab.

LOADS ON ROAD SLABS

In the discussion of loads on road slabs, certain convenient terms will be employed in accordance with the following definitions:

Wheel Load.—When a vehicle is standing upon a horizontal surface with a wheel upon an accurate weighing device, the weight shown is the wheel load of that wheel.

[1] Researches on Structural Design of Highways," *Trans.* A. S. C. E., Vol. 88, p. 264–305, 1925.

Static Wheel Load.—A load that remains in one place on a road slab or that moves very slowly along the road slab, *i.e.*, the wheel load of a vehicle that is standing, or moving very slowly.

Impact Load.—The force applied to the road surface by a vehicle wheel to which vertical acceleration is applied in such a manner as to cause a vertical reaction against the road slab, *i.e.*, when a wheel rolls onto an obstruction on the slab and again when it rolls off the obstruction.

Dynamic Load.—The load produced by rapidly moving wheel loads, including the effects of sudden application and impact.

Equivalent Static Load.—The static load that will produce a stress in a slab equal to that produced by a given dynamic load.

Impact Reaction.—The vertical reaction of the road slab against an impact load.

Highway Loads.—The load that a road slab must carry is that of moving and standing vehicles. The load is applied to the slab, or the wearing surface supported by the slab, over a small area of contact between the tire of the vehicle and the road surface. Over this area of contact it may be assumed that the load is uniformly distributed. For purposes of design it is necessary to know the magnitude and frequency of recurrence of the heavier loads and especially of the maximum load. Regulations in effect in a large number of states in 1928 permit a gross load on four wheels of 28,000 lb. for a four-wheel vehicle, with a maximum of 9,000 lb. on one wheel. There are various restrictions as to type of tire, load permissible when the road is soft, and as to the oad per inch of width of tire.

On the basis of present laws, the designer would assume that the maximum wheel load might be as great as 9,000 lb. Whether the improvement of a highway or a street will be followed by the use of trucks of maximum weight or not is a question to be answered in each individual case.

Trunk highways will always be subjected to loads equal to the legal maximum, and some in excess of the legal limit, but these will be few in number if regulation is reasonably well handled. Most of the county roads are likely to carry a small volume of loads approaching the legal limit. Local roads will carry few vehicles with a wheel load in excess of 3,000 lb.

City streets in strictly residential areas will carry few wheel loads in excess of 3,000 lb. Arterial streets and those in warehouse and wholesale districts will generally be subjected to the

legal maximum wheel loads. Boulevards with load limits imposed by ordinance are easily classified as to wheel load.

The first step then in the design of road slabs is to ascertain the probable maximum wheel load the slab will carry.

Impact.—The extent to which the stress that would be induced in a road slab by a static wheel load is increased when the same wheel load is applied suddenly and under conditions that may cause impact, has been under investigation for a long time[1] and no final conclusion has as yet been reached. It has been shown that if a heavy vehicle is operating with badly worn solid tires, the impact reaction due to the dynamic load may be as much as five times the static wheel load. It has also been shown that vehicles with pneumatic tires operating on smooth surfaces, produce dynamic loads but little larger than the static wheel load. It is to be recognized that the vehicles which approach the legal load limit are the ones most likely to produce destructive impact because they are equipped with solid tires which may become badly worn before they are replaced.

There seems to be ample evidence to show that impact reactions equal to double the static load may be expected from the types of vehicles with solid rubber tires that are now in use on the highways, and that impact reactions equal to one and one-half times the static load may be expected to recur rather frequently. That is, if the static wheel load of such a vehicle is 9,000 lb., the impact reaction for that vehicle when it is moving on fairly good pavements may occasionally reach 18,000 lb. and will frequently amount to 13,500 lb. On exceptionally rough pavements, the impact reaction might reach 45,000 lb. and would frequently reach 22,000 lb. The impact reactions of vehicles with pneumatic tires on ordinarily good pavements will seldom be more than one and three-tenths times the static load and on very rough pavements may be double the static load.

Since the designer is interested primarily in the heavier loads that will be carried by the road slab, he must recognize the probability that these loads will produce impact reactions of considerable magnitude, because it is the heavier loads that are carried on solid rubber tires and these in turn have insufficient

[1] Buchanan, James A., and J. W. Reid, "Motor Truck Impact," *Public Roads*, Vol. 7, No. 4, p. 69, June, 1926.

Fuller, Almon H., and R. A. Caughey, "Experimental Impact Studies on Highway Bridges," *Bull.* 75, Iowa Engr. Exp. Sta., Ames, Iowa, 1925.

absorptive capacity to prevent impact reactions. Specifically, it must be recognized that even on reasonably good road surfaces, vehicles with solid rubber tires will frequently produce impact reactions equal to one and one-half times the static load and will sometimes produce impact reactions equal to double the static load.

Impact Stresses.—In the researches already cited[1] it was shown that the stress produced in the pavement slab by a dynamic load of any intensity is less than the stress produced by a static wheel load of the same magnitude. This is believed to be due to the yielding of the slab under the blow and is in part a function of the stiffness of the slab and in part due to the resistance of the subgrade to movement of the slab. That is, the slab flinches away from the blow and this to some extent reduces the effective magnitude thereof. Research data are entirely too few to permit an exact statement of the relation between impact load and stress, but an analysis of such data as have come to notice indicates that for ordinary problems of road-slab design it is safe to assume the following:

(*a*) Commercial vehicles with solid tires on good pavements frequently produce an impact reaction equal to one and five tenths times the wheel load, accompanied by a stress equal to one and three tenths that which would be produced by a static load equal to the wheel load.

(*b*) Commercial vehicles with solid tires on good pavements occasionally produce impact reactions equal to double the wheel load, accompanied by a stress equal to one and six-tenths times the stress produced by a static load equal to the wheel load.

(*c*) Vehicles with pneumatic tires on good pavements produce impact reactions which are so small that they may be neglected in design because the critical loads are on solid tires. But if a design were based on vehicles with pneumatic tires (streets with restricted traffic) the design should be based on an impact stress equal to that produced by one and three-tenths times the maximum wheel load.

TEMPERATURE STRESSES

Changes in the temperature of the concrete in a road slab cause two distinct types of change in the form of the slab and may introduce stresses of considerable magnitude.

[1] THOMPSON, J. T., "Static Load Tests on Pavement Slabs," *Public Roads*, Vol. 5, No. 9, p. 1, November, 1924.

Linear Changes.—Changes in the temperature of the concrete produce changes in the linear dimensions of the slab; as a whole, the slab becomes longer, wider, and thicker as the temperature of the concrete rises. The change in length and that in width must be taken into account in the design. If the temperature rise is great enough the slab will expand until all of the cracks are closed and the expansion joints (if any) will partially or wholly close. If expansion continues the concrete will pass into a state of compression because it can no longer increase its length (or width). The compressive stress thus produced may be sufficient to rupture the concrete, as is evidenced by those occasional failures of concrete roads or concrete bases known as "blow-ups."

A decrease in the temperature of the concrete causes the slab to shorten and will cause tensile stress in the concrete. If the stress thus produced is greater than the tensile strength of the concrete rupture will occur, but if the concrete is in sufficiently short slabs which are free to move on the subgrade, the stress will be relieved and rupture will not occur. The magnitude of the temperature stresses in concrete slabs due to linear changes in dimensions may be calculated from the standard formula:

$$S = \eta t E \tag{33}$$

where

S = the unit stress resulting from the temperature change,
η = the coefficient of expansion of concrete, usually taken to be 0.000,005,5 for concrete of the quality used for road slabs.
E = the modulus of elasticity for concrete, which may be taken as 4,000,000 for concrete of the quality used for road slabs.
t = the degrees Fahrenheit of the change in temperature of the slab.

Curling.—Another effect of temperature on road slabs arises because of the differences that will often exist in the temperature of the upper and lower surfaces of the slab. When the upper surface is warmer than the lower the slab becomes slightly convex transversely and the middle portion tends to rise from the subgrade. When the upper surface is cooler than the lower the slab becomes slightly concave transversely and the edges tend to rise from the subgrade. It is believed that the longitudinal cracks that are found in wide (12 ft. or more) road slabs are due in part to

this curling action. Of course the same tendency exists in the longitudinal direction but for obvious reasons the slab cannot actually curl in that direction and the result is the introduction of stress in the outer fibers of the slab. The stresses induced in the slab by the curling action may increase or decrease the stresses that exist in the slab because of loads or linear changes in dimensions.[1]

EFFECT OF MOISTURE

Effects similar to those produced by temperature are the accompaniment of change in the moisture content of the concrete in the slab. The concrete *expands* as it absorbs water but there is very little known about the magnitude of the change. In some instances complete saturation of air-dry specimens resulted in a change in length of approximately 0.06 per cent[2] which would be equivalent to that produced by a change in temperature of 100°F. The principal significance of this fact is that, under appropriate conditions, the absorption or loss of water will serve to augment the change in length due to a rise or fall in temperature.

EFFECT OF SUPERIMPOSED WHEEL LOADS

Consider the case of a road slab without cracks and of considerable size, say 20 ft. wide and of a length equal to or greater than the width, resting on any subgrade, and a single wheel load applied 6 ft. or more from the edge. The load tends to push the concrete down into the subgrade and the portion thus distorted will be roughly circular in form (exactly so if the concrete is strictly homogeneous, which it never is) and the portion within the bounding curve will take the form of a dish-like surface of revolution. A cross-section cut by any vertical plane passing through the center of the area of application of the load will take the form shown by Fig. 59.

Since the load is applied approximately uniformly over the area of contact of the tire on the road surface, it might be con-

[1] Westergaard, Henry M., "Analysis of Stresses in Concrete Pavement due to Changes in Temperature," *Proc.* 6th Annual Meeting, Highway Research Board, 1927, p. 201.

[2] Hatt, W. K., "The Effect of Moisture on Concrete," *Public Roads*, Vol. 6, No. 1, p. 14, March, 1925.

Abrams, Duff A., "Effect of Fineness of Cement," *Bull.* 4, Structural Materials Research Laboratory, Lewis Institute, p. 63.

sidered that a prism of concrete under the area of contact and extending through the slab is pushed downward and that the adjacent concrete pulls or pushes against this concrete along radial lines, accompanied by vertical shearing stresses. The actual stress in any horizontal direction in the surface of the prism of concrete, therefore, is the resultant of these radial and shearing stresses. The radial stresses at the top of the slab will be compressive, and at the bottom of the slab will be tensile. If it is desired to determine the stress in the concrete in any one direction, say on a perpendicular plane transverse to the slab, account must be taken of Poisson's ratio of lateral contraction to longitudinal expansion of concrete.

The outer boundary of the portion of the slab deflected by the load is integral with the undistorted part of the slab and the

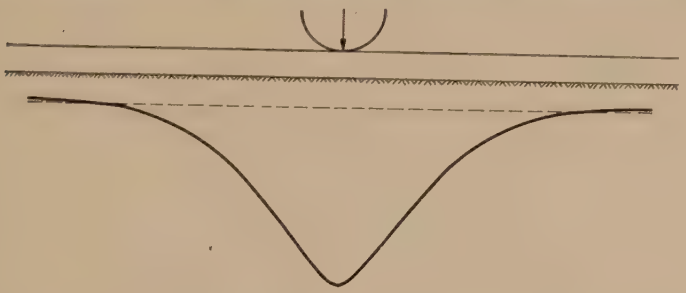


FIG. 59.—Illustrating curvature of road slabs under wheel loads.

vertical section of concrete that bounds the distorted area will be subjected to radial stresses, which at the upper surface of the slab will be tensile and at the lower surface compressive. Like the portion directly under the load, the resultant stress in any direction will be obtained only after taking due account of Poisson's ratio for concrete.

An exact mathematical computation of the stresses in a road slab, resulting from the superimposed wheel loads, has not yet been accomplished, although a close approximation has been achieved by Dr. Henry M. Westergaard[1] which is very useful in determining limiting conditions and balanced design. The analysis is entirely too involved for presentation herein but should be consulted by those desiring to study the nature and

[1] WESTERGAARD, H. M., "Computation of Stresses in Concrete Roads," *Proc.* 5th Annual Meeting, Highway Research Board, Washington, D. C., p. 90, 1925.

magnitude of the stresses induced by loads on road slabs. It shows that the stresses may be somewhat greater than those calculated by Older's Theory of Design (to be presented in another place) under certain conditions, particularly when the load is applied at the extreme edge of a slab.

When a wheel load is applied at the edge of a road slab, whether this edge be the margin of the slab or at a crack or construction joint, the slab is distorted in the same manner as though the load were at a distance from the edge except that the effect is more marked because of the lack of support to the slab on one side of the load. Consequently, the stresses induced are larger for a given thickness of slab when the load is at the edge than when it is in the interior portion of the slab. Similarly when the load is applied at a corner formed by the intersection of a crack or joint with the edge of the pavement, or the intersection of two cracks, the stresses in a slab of a given thickness will be greater than when the load is applied at a distance from free edges.

Westergaard shows[1] that for a wheel load of 10,000 lb. the following stresses would occur in a slab 8 in. thick under like conditions except for the position of the load.

(1) Due to corner load, 325 lb. per square inch in tension.

(2) Due to edge load, 320 lb. per square inch in tension.

(3) Due to load in the interior, 212 lb. per square inch in tension.

It should be noted that the stress in (1) exists in the top of the slab at a section some distance from the load, in (2) and (3) at the bottom of the slab under the load.

SUBGRADE SUPPORT

The portion of the roadway upon which the road slab rests is known as the subgrade. It is apparent that in order to have a condition of equilibrium the summation of the vertical forces acting between the slab and the subgrade must be zero. If the subgrade is very hard it will offer high resistance to displacement of the slab and only a small area of slab will be distorted by a wheel load. If the subgrade is very soft it will offer low resistance to distortion of the slab by wheel loads and a large area of slab will be deflected before sufficient upward pressure is developed to set up a condition of equilibrium. In general, the greater the vertical distortion of the slab by a wheel load, the greater

[1] *Ibid.*

the stress caused by that load, all other conditions remaining unchanged.[1] The amount of support that can be expected from a subgrade, like other factors in this problem of slab design, has been under investigation for a long time, but no wholly satisfactory method of measuring stability has yet appeared. General observation shows conclusively that in any region the soils that compose the subgrades in various sections of a road vary considerably in stability or supporting power under any condition of saturation, and that the soils in one region may differ greatly in bearing power from those in another region. It is known that most soils have much higher supporting power when dry than when wet. Older[2] has shown that with certain soils, at least, there is a certain minimum below which it is impracticable to reduce the water content by drainage devices. Eno[3] in a most exhaustive digest of the researches in this field, supplemented by important researches in Ohio, concludes that there is as yet no basis for accurately predicting the behavior of subgrade soils, although in humid regions a neglect to observe well-known principles of drainage inevitably lowers the supporting power of subgrade soils at certain seasons.

These facts seem to emphasize the need of a good deal of discretion in allowing for subgrade support to road slabs and perhaps argue in favor of designs intended to be stable even when the subgrade is of low supporting power. It has been pointed out (Chap. III) that in any region of considerable precipitation there are sure to be periods when certain areas of subgrade will have low supporting power.

In regions of low annual precipitation and in areas of very sandy soil or of rocky soil, good subgrade support may be assumed unless the road is in proximity to irrigation channels or streams.

The subgrade soil may swell because the entrained water freezes, lifting the road slab as it does so. This action is rarely uniform and the result is that the slab is warped in some places and in others lifted entirely free of the subgrade. The extent of this action is best realized from the fact that the vertical movement due to this cause may be in excess of 3 in. Here again is

[1] *Ibid.*

[2] Older, Clifford, "Bates Experimental Road," *Bull.* 21, Department of Public Works, Illinois (Springfield) 1924.

[3] Eno, F. H., "Highway Subsoil Investigation in Ohio," *Bull.* 39, Engr. Exp. Sta. University of Ohio, Columbus, 1928.

emphasis of the fact that too much dependence cannot be placed upon subgrade support, in the sense that it is uniform throughout the area covered by the slab and unvarying the year around.

In spite of the factors that render somewhat uncertain any estimate of the extent to which subgrade soils will support the road slab, it is clearly recognized that certain soil conditions indicate either good or poor support for a road slab. In any region these conditions may be purely local but come to be recognized, and corrective measures are applied when bad conditions of subgrade soil are noted. These corrective measures may consist of specially designed underdrainage or of treatments of the subgrade soil, the latter consisting principally of layers of gravel, slag or broken stone ballast 6 to 12 in. thick, according to the needs. Most of the state highway departments conduct a subgrade survey to detect unstable sections of road before they construct the high-type wearing surfaces thereon.

Fills at Bridges and Culverts.—It is generally recognized that fills adjacent to bridge abutments and over culverts are likely to continue to settle for a long time after they have been placed. Road slabs are likely to be displaced where they meet a bridge floor because of fill settlement, and thus the bridge approaches become uneven. Often, the slab cracks badly near bridges and over culverts because there has been insufficient care exercised to compensate for the probable settlement. Three steps may be considered with a view to preventing the development of unevenness at bridge approaches:

1. The approach slab may be constructed with one end resting on the bridge abutment and of sufficient thickness to carry the wheel loads even if the fill settles away from the slab.

2. The approach slab may be constructed in short sections so that the ones that settle may be broken out and replaced from time to time until the settlement ceases.

3. The approach slab may be surfaced with asphaltic concrete, which can be replaced from time to time as it becomes uneven from the settlement of the slab.

The slab over culverts may be constructed with sufficient thickness to bridge the span of the culvert if the fill settles away from the slab. Or a short section of slab may be placed over the culvert and doweled to the adjacent slab. This short section is to be broken out and replaced when settlement makes that necessary.

When the slab is to be laid on very rocky soil or ledge rock, gravel, sand, or soil is spread over the rocky surface to insure a reasonably smooth subgrade and uniform bearing.

EFFECT OF WEARING SURFACES

Road slabs of concrete are used extensively as the foundation for a wearing surface of brick, wood, stone, and asphalt and the effect of any one of these surfaces upon the load-carrying capacity and expansion of the concrete base is of considerable importance.

Strength.—The wearing surface can affect the load-carrying capacity of the concrete base by adding to the flexural strength of the cross-section and by distributing the wheel load over an area greater than the area of contact. Cement-grout filled block surfaces undoubtedly do add to the flexural strength and this may be taken into account by considering the wearing surface to be equivalent to a certain thickness of concrete base. The thickness of base is computed as though there was to be no wearing course and then reduced by an amount deemed to be justified by the effect of the wearing surface on the flexural strength of the combined structure. A rule that seems fairly safe is to reduce the computed base thickness by an amount equal to one-half the thickness of the block surface, exclusive of the bedding course.

Block surfaces filled with bituminous materials, and the various hot-mixed bituminous surfaces do not appear to add to the flexural strength of the section sufficiently to justify considering them as affecting the design of the base slab. Probably these surfaces do add somewhat to the flexural strength of the slab under moving loads, but it seems best to disregard it, whatever the amount may be.

Load Distribution.—The area of application of the load to the slab is a factor of some importance, especially with relatively thin slabs, and a wearing surface of any kind does tend to distribute the load to a greater area of slab than the actual contact area between tire and road surface. The various kinds of block surfaces are more effective in this direction than the thinner and more plastic bituminous surfaces. It is also probably true that block surfaces tend to carry loads across cracks in the base in somewhat the same way as dowel steel, which may account for the stability of some of the block pavements with rather thin concrete slabs under them. There is little evidence to indicate that wearing surfaces are effective in minimizing the impact

reactions on the base course even though several inches of surface may intervene between the area of application of the blow and the slab.

All of the dependable evidence now available tends to point to the necessity of designing concrete slabs that are for foundation courses on the same basis as slabs to be used as wearing surfaces. Undoubtedly such a slab has a somewhat higher factor of safety than is introduced into the design, but the effects of the wearing surface are so difficult to measure and so variable that they had better be neglected in the design.

Temperature Effects.—It seems to be clear that a wearing course of appreciable thickness on a concrete slab tends to insulate the concrete from those temperature conditions that are the cause of curling. But the concrete slab will be subjected to changes in temperature with the seasons to about the same extent as slabs not covered with wearing courses. Contraction cracks will form and in many cases will extend through the wearing course. Buckling due to expansion is not uncommon and usually carries with it the rupture of the wearing course.

EFFECT OF EMBEDDED STEEL

The utility of embedded steel in concrete road and pavement slabs has been satisfactorily established by numerous studies[1] of the subject and its use is almost universal. While the benefit of steel is proven beyond question, no method of calculating the exact amount or distribution of the steel in the slab has as yet appeared. Consequently, there is a good deal of variation in the steel requirements of various specifications.

Purpose of Reinforcement.—Reinforcement is used in concrete road slabs, not to add to the flexural strength, but to transmit shear at cracks and joints and to prevent cracks from opening to an extent that complicates the maintenance of the pavement. If cracks develop in such a manner as to form corners in the interior portion of the slab, these are as much a source of weakness as they would be if they were at the margin of the slab. The reinforcement is presumed to provide dowels that will eliminate the possibility of independent corners or edges being formed in the interior portion of the slab as well as corners at the

[1] HOGENTOGLER, C. A., "Economic Value of Reinforcement in Concrete Roads," *Proc.* 5th Annual Meeting, Highway Research Board, Part II, Washington, D. C., 1925.

margin. This requires that the bars be close enough together to accomplish that purpose. Transverse cracks are sure to develop unless contraction joints are provided, and possibly even then, and the longitudinal steel is intended to keep these from widening and to dowel together the two parts of the slab so they will deflect alike under loads.

Transverse Steel.—The purpose of the transverse steel is to dowel together the adjoining portions of the slab along longitudinal cracks, preventing the crack from widening and assisting to transmit loads from one part of the slab to the adjacent part on the other side of the crack. The load is transmitted in part by friction between the faces of the concrete in contact at the crack and in part by the steel. Thus the steel is subjected to shear.

The maximum load to be transmitted will be one half of the equivalent static load produced by the heaviest vehicle that uses the road. This equivalent static load will be about one and one-half times the wheel load for good concrete surfaces, amounting in extreme cases to 13,500 lb. or more on trunk highways and certain classes of streets. Under ideal conditions approximately half of this load, or 6,750 lb., is transmitted to the adjacent slab. Since the maximum load does not recur frequently a high unit shearing stress may be permitted, perhaps as much as 20,000 lb. per square inch, and a part of the load will be transmitted by friction; therefore, it seems that ½-in. round bars will be adequate for transverse dowels.

The transverse bars should be close enough together to prevent excessive deflection between bars. The curvature of the slab is rather sharp near the load (see Fig. 59), and the best evidence now available indicates that the spacing of transverse dowel bars should be about 2 ft. in order to be most effective.

If the slab is divided into 10-ft. lanes by longitudinal joints, the probability of longitudinal cracks forming between the longitudinal joints is remote and the dowel bars may be used only across the longitudinal joints. For this purpose deformed bars are preferable, although plain bars are believed to be satisfactory. Nevertheless, transverse bars extending the full width of slab add a very desirable factor of safety.

If the reinforcement is in the form of a woven or welded fabric, the size and spacing of the transverse members is adjusted to provide ample dowel steel across longitudinal cracks that may

occur. There appears to be some advantage in having the steel well distributed so long as the individual members are heavy enough to resist corrosion. This is believed to require fabric weighing in excess of 50 lb. per 100 sq. ft. The fabric type of reinforcement has not been widely used across longitudinal joints because of construction difficulties that developed in connection with the older forms of joint but there appears to be no reason why it should not be used with the dummy[1] type of joint.

Longitudinal Steel.—Longitudinal steel is used primarily to provide dowels at transverse cracks which are always to be found in road slabs of concrete. Since there is no predicting where these cracks will appear, the steel is placed so as to be continuous except across expansion joints. When contraction joints are provided, the longitudinal steel undoubtedly serves to minimize the amount of transverse cracking between joints, but the amount of steel is too small to have any considerable effect on the spacing of the contraction joints. Plain round bars are used for longitudinal reinforcing or, where fabric is used, the longitudinal members are designed to serve the purpose. There is no very well established standard for the amount of longitudinal steel, and no way to calculate it, except that the quantity must be sufficient to carry shear across the cracks that develop. Since the wheel loads come near the edges of the traffic lanes, it is customary to place the longitudinal bars from 6 in. to 1 ft. from each edge of each 9- or 10-ft. lane. Sometimes a third bar is placed at the middle of the lane. In most designs, ¾-in. smooth round bars are used, but some plans provide for the use of ½-in. round bars. Deformed bars are not used for longitudinal reinforcing.

Value of Dowel Steel.—Investigations of the deflection of concrete road slabs indicate that when adjacent slabs are connected by steel dowel bars, the capacity of the doweled joint to transmit shear varies greatly, and that in consequence the deflection on the load side of a crack may be greater than on the unloaded side of the crack. In some cases investigated, not more than 5 per cent of the load was transmitted across the crack by shear and friction and in other instances as much as 40 per cent was transmitted. This variation is doubtless due to the extent to which the crack opens when the slab shortens from

[1] Described on page 253.

the effect of lowered temperature and shrinkage. The load transmitted across these doweled cracks is believed to be in excess of 25 per cent of the total in most cases.

A further consideration is that Westergaard's analysis indicates that the critical stress in a road slab of concrete is developed when the load is at the edge of the slab and is a tensile stress directly under the load in the lower surface of the slab. Of course this stress develops only when the slab is continuous, that is, there are no transverse cracks, and consequently dowel steel does not enter into the problem except as it tends to prevent the formation of cracks. Older's theory does not concern itself with this condition.

THEORY OF DESIGN OF SLAB CROSS-SECTION

The early concrete road slabs were constructed of such thickness and strength as experience indicated to be necessary to

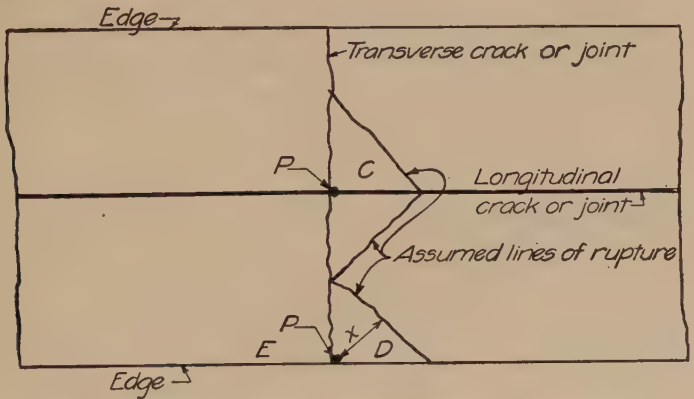


FIG. 60.—Illustrating Older's theory of design of concrete slabs.

carry the anticipated loads. Upon the completion of the Bates Experiment and various collateral investigations, a serious attempt was made to develop a theoretical basis for the design of road slabs. The first of these attempts was the outgrowth of the Bates Road tests and is known as Older's theory of design. Subsequent investigations, by the Bureau of Public Roads, led to the conclusion that Older's theory did not cover all of the conditions that contribute to failure and that the true stresses in certain cases were more nearly indicated by Westergaard's analysis. It seems clear that additional researches will be neces-

sary before an exact theory of design can be presented. Meanwhile, the theories offered by Westergaard and Older afford a means of developing and checking the design of road slabs that is as nearly accurate as knowledge of the loads and the flexural strength of the concrete justifies.

Older's Theory of Design.—If the load is placed at D (Fig. 60), at the edge of the slab near a transverse crack or expansion joint and the pavement is of plain concrete, the slab will tend to rupture along an irregular surface at some distance from the load, as shown. The distance will vary with the subgrade condition, but in most of the failures observed it will vary from 2 to 6 ft.

Case I.—It is assumed that the break may occur at an angle of 45 deg. with the edge of the pavement, which would give the smallest resisting moment, and that the corner carrying the load is free to deflect independently of the adjacent slab.

The bending moment of the load is

$$M_1 = Px.$$

The resisting moment of the plain concrete is

$$M_r = \frac{fI}{c} = \frac{f}{c} \times \frac{t^3 x}{6} = \frac{1}{3} ft^2 x.$$

Where

P = one wheel load in pounds, including impact allowance, if any is made.
f = flexural modulus of rupture of the concrete.
I = moment of inertia of the plane of rupture.
t = thickness of the slab.

$$c = \frac{t}{2}.$$

Then

$$Px = \tfrac{1}{3} ft^2 x$$

$$t = \sqrt{\frac{3P}{f}}. \qquad (34)$$

Case II.—If sufficient steel is embedded in the concrete and across the joints to insure that corner E will deflect with corner D, the resisting moment will be doubled and the formula for thickness becomes

$$t = \sqrt{\frac{1.5P}{f}}. \qquad (35)$$

Case III.—Consider a wheel load placed in the middle portion of the slab as at C, and that there is sufficient steel in the slab to carry the load across any cracks that may have formed. It may then be considered that the resisting moment is now double that of Case II and the formula for thickness becomes

$$t = \sqrt{\frac{0.75P}{f}}. \tag{36}$$

Formula 36 would be applicable only when the slab is large enough to insure that the lines of rupture lie wholly within the area of the slab.

Basis of Design.—These various considerations suggest an approximate method of design that appears to be adequate so far as present knowledge affords a basis for judgment.

The edge thickness required for a concrete road slab may be calculated from the formula $t = \sqrt{\frac{3P}{f}}$ and this applies whether dowel steel is used or not, but if dowel steel is used it introduces an additional factor of safety. The edge thickness thus calculated must be carried throughout the slab if no dowel steel is used.

If dowel steel is used the thickness in the interior portion of the slab will be calculated from the formula $t = \sqrt{\frac{1.5P}{f}}$, or the thickness of the interior portion of the slab will be about 0.7 of that at the edge.

Since neither of these design formulas was developed on a basis that takes account of tensile stress in the portion of the slab directly under the load, it is necessary to check the design, as developed above, against the tables prepared by Westergaard, for the purpose of showing the tensile stress in the area directly under the load.

Within the limits of load and flexural strength of concrete that are usually encountered in the design of road slabs, the suggested method of design provides a slab that is of ample strength to resist the stresses produced directly under the load.

PROCEDURE IN DESIGN

It is convenient to think of the design of road slabs of concrete as consisting of three preliminary steps and the actual computation of slab thickness. The three preliminary steps are:

1. Determination of the equivalent static load upon which the design should be based.

On the basis of data presented in a previous section the equivalent static load to use for vehicles with solid tires is one and six-tenths times the actual wheel load, and the equivalent static load to use with pneumatic-tired vehicles appears to be one and three-tenths times the actual wheel load. It is rarely true that this factor for vehicles with pneumatic tires is the determining load.

2. To ascertain the probable flexural modulus of rupture of the concrete and from that calculate the safe working flexural strength.

It seems to be reasonably well established that the safe working flexural strength may be assumed at 55 per cent of the flexural modulus of rupture. The flexural modulus of rupture may be known from previous tests of the mixture and aggregates it is proposed to use; it may have to be determined by laboratory tests of materials and mixtures that are to be employed; or it may be estimated from available data as to the compressive strength of comparable mixtures.

3. To decide whether the slab should be of uniform thickness or of the thickened-edge type.

If the conditions of use indicate that the critical loads will travel with a wheel at the edge of the slab, the thickened-edge type will be used; otherwise, the slab will be of uniform thickness.

The computation of thickness is then made with the several factors in the design formulas fixed on a basis of the conclusions reached in the preliminary considerations.

ILLUSTRATIVE DESIGNS

Case I.—Wheel load 8,000 lb. on solid tires. Flexural modulus of rupture of the concrete 600 lb. per sq. in. Concrete road slab 20 ft. wide for a trunk highway.

Type of section, thickened edge with dowel steel.

$$P = 1.6 \times 8{,}000 = 12{,}800 \text{ lb.}$$

$$f = 600 \times 0.55 = 330 \text{ lb. per square inch}$$

$$\text{At edge, } t = \sqrt{\frac{3 \times 12{,}800}{330}} = 10.8 \text{ in. say } 10.5 \text{ in.}$$

$$\text{In interior portion, } t = \sqrt{\frac{1.5 \times 12{,}800}{330}} = 7.6 \text{ in., say } 7.5 \text{ in.}$$

If the stress under the wheel load is checked for the above conditions, it will be found that the tensile stress under the load at the edge is about 270 lb. per square inch and in the interior of the slab about 270 lb. per square inch. Therefore, it may be concluded that the design is well balanced and the stresses at all sections within the limits prescribed.

Case II.—Wheel load 6,250 lb. on solid tires. Flexural modulus of rupture of the concrete 600 lb. per square inch. Pavement slab 40 ft. wide with integral curb, on a street upon which it is permitted to park vehicles along curb.

Type of section, uniform thickness with dowel steel.

$$P = 6{,}250 \times 1.6 = 10{,}000 \text{ lb.}$$
$$f = 600 \times 0.55 = 330 \text{ lb. per square inch}$$
$$\text{Thickness} = \sqrt{\frac{1.5 \times 10{,}000}{330}} = 6.74 \text{ in.}$$

Upon checking this slab for tensile stress in the portion of the slab directly under the load it is found that the stress is approximately 220 lb. per square inch in tension. If the assumption is correct that because of the practice of permitting vehicles to be stored along the curb, no consideration need be given to maximum oads along the edge, then a slab as designed is adequate.

Case III.—Wheel load 5,000 lb. on solid tires (double-deck bus). Flexural modulus of rupture of concrete 400 lb. per square inch. Type of section, heavy traffic mixture sheet asphalt 2 in. thick with asphaltic concrete binder course 1½ in. thick placed on plain concrete (no dowel steel) slab of uniform thickness. Curbs of concrete without attached concrete gutter.

$$P = 5{,}000 \times 1.6 = 8{,}000 \text{ lb.}$$
$$f = 400 \times 0.55 = 200 \text{ lb. per square inch}$$
$$t = \sqrt{\frac{3 \times 8{,}000}{220}} = 10.4 \text{ in. (use 10 in.)}$$

If dowel steel were used in this pavement base, the edge thickness would be 10 in. and the thickness in the interior portion $0.7 \times 10 = 7$ in. Many designers would assume that the 2-in. wearing course added sufficient flexural strength to the pavement to warrant reducing the calculated thickness of the base 1 in., whether the uniform-thickness type or the thickened-edge type were used.

Case IV.—Wheel load 10,000 lb. on solid rubber tires. Flexural modulus of rupture of the concrete 700 lb. per square inch. Type of pavement, asphalt-filled brick surface 3 in. thick, sand bedding course, and concrete base. Granite curbs. Location wholesale and warehouse district.

Type of section, thickened edge with dowel steel.

$$P = 10{,}000 \times 1.3 = 13{,}000 \text{ lb.}$$
$$f = 700 \times 0.55 = 385 \text{ lb. per square inch}$$
$$\text{Edge thickness, } t = \sqrt{\frac{13{,}000 \times 3}{385}} = 10 \text{ in.}$$
$$\text{Interior thickness} = \sqrt{\frac{13{,}000 \times 1.5}{385}} = 7 \text{ in.}$$

It should be noted that the combination of the asphalt-filled surface and sand-bedding course is assumed to justify reducing the equivalent static load from one and six-tenths times the wheel load as used in other cases, to one and three-tenths times the wheel load. That is to say, it is assumed that the dynamic load will be but 50 per cent greater than the static load, instead of being double the static load.

Case V.—Wheel load 3,000 lb. on solid rubber tires. Flexural modulus of rupture of the concrete 500 lb. per square inch. Type of pavement, concrete with dowel steel and integral curb on a residential street which is not an arterial route.

Type of section; A slab of uniform thickness with dowel steel.

$$P = 3{,}000 \times 1.6 = 4{,}800 \text{ lb.}$$
$$f = 500 \times 0.55 = 275 \text{ lb. per square inch.}$$
$$t = \sqrt{\frac{4{,}800 \times 1.5}{275}} = 5.1 \text{ in. (use 5.5 in.)}$$

Case VI.—Wheel load 3,000 lb. on pneumatic tires. Flexural modulus of rupture of concrete 500 lb. per sq. in. Type of pavement, 2 in. of asphaltic concrete on portland-cement concrete base. Restricted traffic. Combined concrete curb and gutter. No parking along curb.

Type of section, uniform thickness without dowel steel in the concrete base

$$P = 3{,}000 \times 1.3 = 3{,}900 \text{ lb.}$$
$$f = 500 \times 0.55 = 275 \text{ lb. per square inch.}$$
$$\text{Base thickness} = t = \sqrt{\frac{3 \times 3{,}900}{275}} = 6.5 \text{ in.}$$

Alternate type of section, uniform thickness with dowel steel and with combined curb and gutter doweled to the concrete base.

$$\text{Base thickness} = t = \sqrt{\frac{1.5 \times 3{,}900}{275}} = 4.6 \text{ in.}$$

In neither case would the base thickness be reduced below that calculated as a concession to the possible strengthening due to the wearing surface.

Author's Note: It has been suggested that this book should include a discussion of the design of concrete mixtures for road slabs. He feels, however, that the subject is entirely too broad for presentation in the limited space that might be devoted to the subject herein. Moreover, it has been presented admirably by more able experts in a long series of bulletins and papers that have appeared during the past ten years. A brief discussion of some special aspects of the design of mixtures is presented at appropriate places in the chapters dealing with certain types of pavements.

CHAPTER XII

PORTLAND-CEMENT CONCRETE ROADS AND PAVEMENTS

Portland-cement concrete was laid as the wearing surface for streets in Grenoble, France, in 1876; in Bellefontain, Ohio, in 1894, and in LeMars, Iowa, in 1904, and these pavements are still in service. It was not until about 1910, however, that this type of pavement began to attract widespread attention among engineers and public officials in the United States. Since that time the concrete pavement has increased in importance at a phenomenal rate and an immense amount of research has been undertaken with a view to standardizing its construction. While a few installations have been made in which relatively small precast blocks or slabs of concrete were used, the more common method has been to construct the pavement in place in slabs of considerable area.

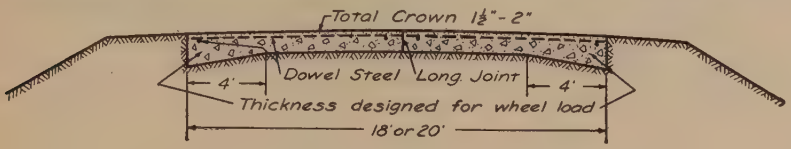
CROSS-SECTIONS

The application of the principles of design that were discussed in Chap. XI lead to a number of types of cross-sections, adapted to meet the needs of the traffic and the drainage conditions that are encountered on normal paving projects. These are shown in Fig. 61.

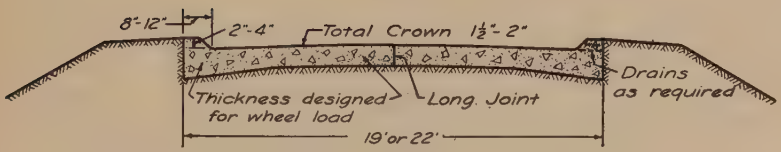
Type I.—The most widely used cross-section for rural highways is the thickened-edge type without marginal curb. For rural highways remote from metropolitan centers the usual dimensions are 9 in. at the edge and 7 in. in the interior portion, the edge thickness decreasing to the middle thickness in a distance of 4 ft. Some mileage of 10–8–10 section has been built, which will carry a wheel load of 10,000 lb. with ample allowance for impact. Probably there are areas in which a 12–9–12 slab is required, which will carry a wheel load of 13,000 lb. with suitable allowance for impact.

Type 2.—The marginal curb sections is used for rural highways where topographical conditions make it advisable to carry

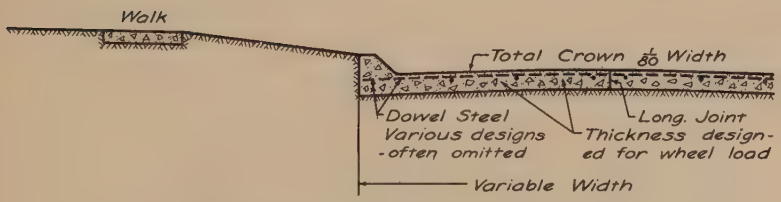
drainage water on the pavement slab until it can be delivered to the side ditches at places where it can be disposed of without



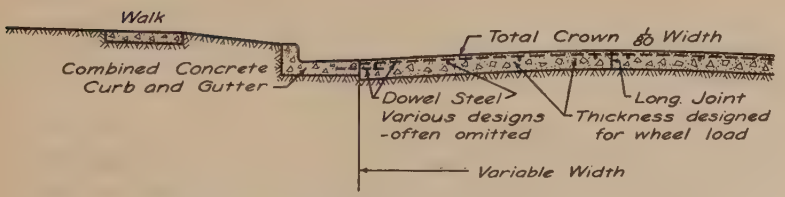
Two Lane Highway Type



Two Lane Highway Type



Integral Curb Type Street Pavement



Street Pavement With Combined Concrete Curb and Gutter

FIG. 61.—Types of cross section for concrete roads and pavements.

introducing troublesome problems of erosion. This section is used in cuts to reduce the width as well as to eliminate erosion

problems; on steep grades where ditch erosion would occur if the usual side ditch were used; and on embankments where erosion would result if storm water were allowed to flow over the edge. Sometimes a section with only one curb is used along the inside of a curve to prevent the traffic from cutting in on the shoulder along the pavement slab.

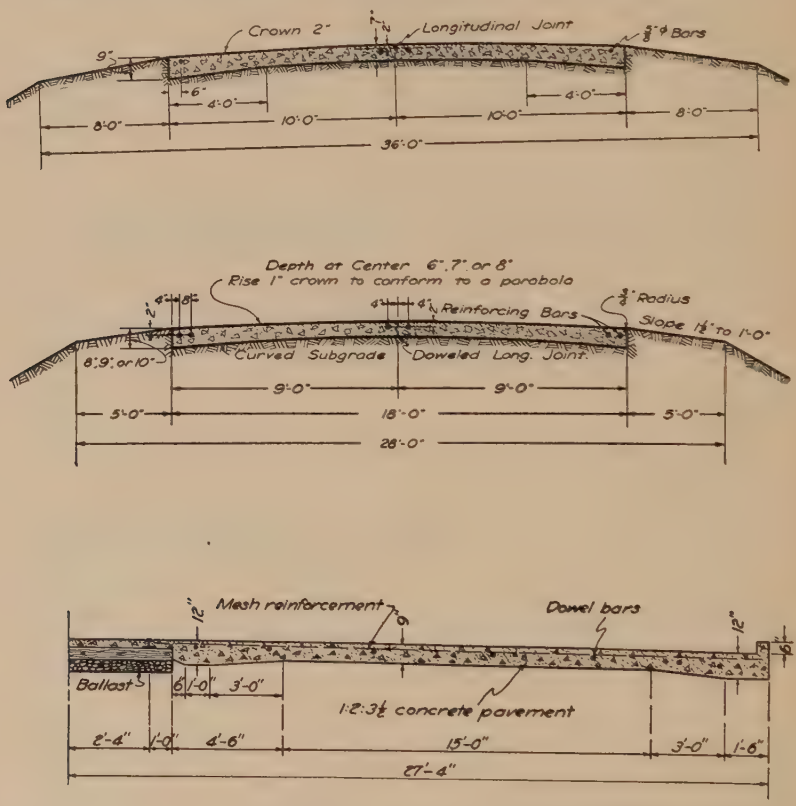


FIG. 62.—Upper, Iowa Standard Section; middle, Pennsylvania Section; lower, section for street with car track.

In this type of slab no reduction in edge thickness is made to take advantage of the strengthening effect of the marginal curb. The curb is simply added to whatever may be the standard curbless section.

Type 3.—The street-pavement section with integral curbs is widely used in municipal practice and since there is little traffic near the curb and the curb is of sufficient size to add materially

to the stability of the edge of the pavement, the cross-section of uniform thickness is generally employed for city streets.

Type 4.—The concrete pavement with a combined concrete curb and gutter is sometimes used in municipal work instead of the integral curb type. To give the necessary stability at the edge of the pavement slab, the pavement slab must either be designed with the thickened edge or else doweled to the gutter slab.

DESIGN OF EXPANSION AND CONTRACTION JOINTS

There is a lack of uniformity in present practice with reference to the spacing and design of expansion and contraction joints due to the uncertainties that exist with reference to the fundamental basis upon which the design should rest. The following discussion is an attempt to present such facts and principles as are at present recognized to some degree and to indicate a method of studying the problem. Additional research will clear up some of the doubtful factors.

Expansion Joints.—It has been pointed out that concrete slabs will change dimensions with a change in temperature or in moisture content. As a rule, the change in the length of the slab is the effect that is of most significance to the road builder.

If a road slab were constructed in short independent sections, each free to expand and contract at will, no serious stresses would be set up in the slab by changes in linear dimensions. But to construct a road slab in this manner would introduce an objectionable number of transverse joints, which are difficult to construct so that they are "easy-riding" and impossible to construct when the slab is finished by machine except by skipping sections of the slab with the machine, then inserting the joint and finishing the adjacent portion of the slab by hand methods. No method of constructing rural highway slabs would be accepted if it interfered with machine-finishing. City pavements that are too wide for machine-finishing must of necessity be hand-finished and the insertion of expansion joints offers no special construction problem other than that of securing satisfactory smoothness at the joint.

If it is desired to employ expansion joints to eliminate the compressive stress that would otherwise develop as the slab tends to increase in length, the spacing of the joints should be such that at no section between joints will the compressive stress

reach an intensity that would eventually result in rupture through fatigue.

In the illustrative problems that follow, the several factors are based on a 9–7–9 concrete road slab 20 ft. wide and concrete having an ultimate tensile strength of about 300 lb. per square inch at an age of 28 days.

If the expansion joints are L ft. apart, a section midway between the expansion joints may be assumed to remain stationary throughout all of the cycles of temperature and moisture, while the half of the slab on each side the mid-section slides backward and forward over the subgrade as the slab changes its linear dimensions from temperature and moisture effects.[1] This movement is resisted by the friction between the slab and the subgrade. The unit compressive stress set up at the mid-section of a slab L ft. long will be

$$S_c A = \frac{fWL}{2} \text{ and hence } L = \frac{2S_c A}{fW}, \tag{37}$$

in which

S_c = the compressive stress in pounds per square inch.
A = the cross-sectional area of the slab in square inches.
f = the coefficient of friction between the slab and the subgrade.
W = the weight of the slab in pounds per foot of length.
L = the length of the slab between expansion joints, in feet.

The spacing of expansion joints can be determined from Equation 37.

The only doubtful factor in Equation 37 is f, since all of the others would be known for any particular design. f has been measured[2] for a few conditions and seems to vary between 1 and 2.

As an example of the application of Equation 37, let S_c = 1,500 lb. per square inch, A = 1,776 sq. in., W = 1,850 lb., and f = 1.5, then

$$L = \frac{(2)(1{,}500)(1{,}776)}{(1.5)(1{,}850)} = 1{,}925 \text{ ft.}$$

So far as known to the author, the first published exposition of the general principles with reference to contraction joints and expansion joints was in a report by A. T. Goldbeck in *Public Roads*, Vol. 6, No. 6, p. 117, August, 1925. That report is the basis of the material presented herein.

[2] Goldbeck, A. T., "Friction Tests of Concrete on Various Subbases," *Public Roads*, Vol. 5, No. 5, p. 19, July, 1924.

It will be apparent that the full magnitude of the friction between the slab and the subgrade develops as soon as there is a small movement of the slab which might follow a small change in temperature or moisture. If the temperature change is great, the elongation of the slab will be correspondingly large and the width of joint required may be so great as to be objectionable. It is therefore necessary to investigate that factor before deciding upon the spacing of the expansion joints.

The width of expansion joint required when the joints are L ft. apart is,

$$J = (L)(T)(0.000,005,5) + L\eta' \qquad (38)$$

in which

J = the width of the joint in feet.
T = the maximum rise in temperature in degrees Fahrenheit above that at the time the pavement was constructed.
η' = the coefficient of expansion due to absorption of water.

If the temperature at the time the pavement was constructed was 60°F. and the maximum summer temperature reaches 115°F., and no account is taken of expansion due to moisture, the length of slab, 1,580 ft., the joint width would need to be 0.58 ft., or 7 in. This is too wide to be readily maintained, and, accordingly, the spacing should be decreased to provide a joint of suitable width.

As a general rule, the maximum temperature rise and the maximum absorption seldom occurs simultaneously but it is apparent that in tropical climates the two would supplement each other to some extent. It is quite possible for absorption to cause as much expansion as a change of 100°F., or more, in temperature, under certain conditions.

It is apparent that the spacing of the expansion joints will depend upon two factors; the width deemed satisfactory and the allowable stress in the concrete. In city pavements it is undesirable to space the joints so far apart as to necessitate more than ½ in. of movement in the slab. For rural highways the movement may be as much as 2 in.

Contraction Joints.—Where a concrete slab of length L' decreases in length there is again a mid-section that is stationary and the length $\frac{L'}{2}$ is drawn along the subgrade and tensile stress is

set up in the slab. If no longitudinal steel is used in the slab, spacing L' of the contraction joints will be as follows:

$$AS_t = \frac{fWL'}{2}, \text{ or } L' = \frac{2AS_t}{fW}, \tag{39}$$

in which the factors are as in Equation 37 except S_t which is the safe tensile strength of the concrete.

If the concrete is kept moist during the curing period, especially for the first week, S_t may be taken as 50 lb. per square inch. The spacing of the contraction joints, or cracks, if no joints are used, will be

$$L' = \frac{(2)(1{,}776)(50)}{(1.5)(1{,}850)} = 64 \text{ ft.}$$

If longitudinal steel is used in the slab the tensile strength of the steel is added to that of the concrete and when stress in the steel is kept well below the yield point, no cracks will form between contraction joints. The spacing of contraction joints for this condition will be

$$AS_t + a\frac{E_s}{E_c}S_t = \frac{FWL'}{2}$$

$$L' = \frac{2\left(AS_t + a\frac{E_s}{E_c}S_t\right)}{fW} \tag{40}$$

in which

L' = the spacing of contraction joints in feet.
S_t = the safe tensile strength of the concrete in pounds per square inch.
A = the cross-sectional area of the concrete slab, in inches.
E_s = the modulus of elasticity of the steel.
E_c = the modulus of elasticity of the concrete.
f = the coefficient of friction between slab and subgrade.
W = the weight of slab in pounds per foot of length.
a = the cross-sectional area of the steel, in square inches.

To illustrate the application of Equation 40, let it be assumed that the several factors have the following values:

a = 1.77 sq. in. (four ¾ in. round bars).
S_t = 50 lb. per square inch.
f = 1.5.
W = 1,850 lb.
A = 1,776 sq. in.
$\frac{E_s}{E_c}$ = 8.

Then

$$L' = 2\frac{(1{,}776)\ 50 + (1.77)(8)(50)}{(1.5)(1{,}850)} = 65 \text{ ft.}$$

It will be noted that the longitudinal steel has little effect on the spacing of contraction joints because of the relatively small area of steel in the cross-section. The steel is used primarily to transmit loads across the cracks and joints, but does serve to prevent contraction cracks between contraction joints, the steel elongating enough under stress to permit the joint to open slightly. The bond between the steel and the concrete is broken for a short distance each side of the contraction joint so that several inches of the bar can elongate as the joint opens.

The longitudinal steel does not extend across the expansion joints. In order to provide dowels, a special provision is made whereby bars about 3 ft. long are inserted in such a manner that one-half of the bar is free to slip in the concrete as the joint opens and closes.

Summary.—The spacing of expansion joints is determined by calculating how long the slab may be without dangerous compressive stresses developing in the concrete and without necessitating a joint that is too wide for satisfactory maintenance. Whether the width of joint or the stress limitation will control depends upon the temperature and moisture factors.

Special dowel construction is required at expansion joints because the dowel bars must be able to slip back and forth as the joint changes width.

Contraction joints are used to eliminate erratic transverse cracks in the slab between expansion joints. If joints are not used, cracks will appear.

The coefficient of friction between the slab and the subgrade has not been extensively investigated and the safe procedure is to use a fairly high value for computations unless the true value is known for the specific project.

The allowable tensile stress in the concrete depends upon curing methods and weather conditions, but it is recognized that contraction cracks are likely to form while the concrete is curing and has low tensile strength unless great care is taken to keep moisture in the concrete so that it will not contract until it has attained some tensile strength.

Details of Expansion Joints.—An expansion joint is a gap in the pavement slab which is filled with some plastic substance which

will squeeze out of the joint when the ends of the slab creep toward each other as the slabs expand. These gaps or joints are designed with widths ranging from ½ to 2 in. and extend entirely through the slab so as to effect a complete separation.

If a slab is designed on the basis of the use of dowel steel to carry the deflection across cracks and joints, the expansion joint must be provided with dowel bars to provide the necessary connection between the adjoining ends of the slabs. But both ends of the dowel bars must not be bonded in the concrete, else there will be no way that they can slip as the slabs move and as the joints close up the bars will buckle and probably rupture the concrete. The necessary slippage is provided for by placing sleeves of light metal tubing over one end of each bar, the sleeve extending from the joint into the concrete far enough to provide ample end play for the bars. The longitudinal reinforcing in the slab does not extend across the expansion joint.

Some designs omit the dowel bars across expansion joints and give stability to the slab by using a thickened section along the joint much like that used along the edge of the 9–7–9 rural highway type.

Fillers for Expansion Joints.—The most common type of joint filler is the premolded sheet of filler which is furnished in a variety of thicknesses. It consists of a sheet of bituminous mastic between tough paper facings and is set in place before the concrete is poured. An installing device holds the joint filler to line and grade so the finishing machine can operate over the top of the filler. After the finishing operations have been completed, the installing device is removed and the concrete along the joint finished with an edging tool. This type of joint is very widely used for concrete roads and pavements.

There is a limited use of the poured expansion joint in concrete pavements. This joint is constructed by setting a form board in position before the concrete is placed and after the concrete has set the form is removed and the joint is poured with a suitable bituminous filler.

With either type of expansion joint it is good practice to finish the concrete carefully at the joint to make sure there is neither a ridge nor a depression and to smooth the concrete along the filler with an edging tool so as to minimize spalling which may occur if the slab does not have a rounded edge.

Pavements on country roads require expansion joints about every 500 ft. and at the beginning and end of horizontal and vertical curves, and at the ends of bridges. In city pavements expansion joints should be placed at each intersection at the beginning of the radius curb, and if the blocks are more than 300 ft. long, at the middle of the block.

Details of Contraction Joints.—While the expansion joint relieves the stress that would otherwise develop as the slab expands, it will not relieve the tensile stress that develops as the slab contracts unless the expansion joints are quite close together. In municipal practice it is not uncommon to space expansion joints about 35 ft. apart and to omit contraction joints.

When a pavement slab cracks because the tensile strength has been exceeded due to contraction of the concrete, the main cracks are irregular and ragged and in addition minute branch cracks form which are the beginnings of spalling that develops later. To avoid the necessity for frequent expansion joints or the alternative of irregular cracks, contraction joints are used. These may be provided by introducing planes of weakness, sometimes called dummy joints, in the concrete slab or by placing the concrete around and over joint-forming plates set vertically on the subgrade before the concrete is placed.

Planes of Weakness.—One method of providing contraction joints, then, is to introduce planes of weakness across the slab.[1] This is accomplished by driving a wedge-shaped metal strip into the green concrete after the other finishing operations have been completed. These strips are about 2 in. wide and ½ in. thick at one edge and tapered to a blunt edge at the other, and are long enough to reach across the slab or half-way across the wide slabs. They are placed vertically along a guide plank laid across the slab so the joint will be straight, and are driven into the green concrete until level with the surface. They are sufficiently flexible to conform to the slight crown of the pavement. The concrete along the joint former is finished with an edging tool with a radius of about ½ in. and the surplus concrete carefully removed from the vicinity of the joint. As soon as the concrete hardens the metal plate is removed from the joint and the space filled with a bituminous material. This reduction in

[1] "Dummy joints: Their Construction and Tools as Used Along the Pacific Coast." *Concrete Highways and Public Improvements*, Vol. 12, No. 3, March, 1928, p. 54, and Vol. 12, No. 4, April, 1928, p. 78.

the effective cross-section of the concrete slab insures that most of the contraction cracks will form at one of the joints and will not show at the surface. The longitudinal reinforcing steel extends across these joints but low enough in the slab to permit forming the joint. When the crack opens the steel stretches and necks down slightly for a distance on each side of the joint.

Joint Formers.—Another method of forming contraction joints is to set a thin metal plate vertically on the subgrade and extending entirely across the subgrade, prior to placing the concrete. The plate is too narrow to reach to the surface of the concrete and a finishing machine can be operated on the concrete without disturbing the former. When the concrete contracts it ruptures the thin layer of concrete above the edge of the plate, thus forming a contraction joint that will be fairly straight across the slab and, since no great strain is required to rupture the concrete, there are few branch cracks formed. The longitudinal steel in the concrete is continuous, being inserted in holes in the joint-forming plates or being dropped into slots therein. Some types of these plates are shaped to form a tongue-and-groove joint, thus strengthening the joint against load effects.

In some instances the joint plate is located by means of a trowel, after the slab has been finished, and a neat shallow groove is formed in the concrete surface directly over the plate by means of a finishing tool. This insures against a ragged crack when the concrete ruptures. The usual spacing of contraction cracks is about 25 ft., but there is no accepted standard spacing. The joints should be close enough together to effectually prevent sizable contraction cracks.[1]

LONGITUDINAL JOINTS

It has been noted that, due possibly to the tendency for slabs to curl, longitudinal cracks generally appear in concrete road slabs more than 12 ft. wide. These cracks are not only unsightly, but also are difficult to maintain if they are in the zone of the heaviest wheel wear. To minimize this difficulty there has been rather general adoption of the longitudinal joint for concrete road slabs in excess of about 12 ft. in width.

[1] GOLDBECK, A. T., "The Interrelation of Longitudinal Steel and Transverse Cracks in Concrete Roads," *Public Roads*, Vol. 6, No. 6, p. 117, August, 1925.

For widths up to about 30 ft. one joint is inserted along the center line of the slab. If the width exceeds about 30 ft. longitudinal joints are used to divide the slab into traffic lanes about 10 ft. wide. This joint is not to provide for expansion but on the contrary is constructed like a contraction joint. There are two types of these longitudinal joints which are identical in design with the two types of contraction joints, *i.e.*, the joint formed by a thin metal plate and the one formed by introducing a plane of weakness into the concrete slab.

A little consideration of the effects of wheel loads applied to the slab near the longitudinal joint will make it apparent that either the edge of the slab should be thickened along the joint, or dowel steel should be used to transmit part of the load to the adjacent slab on the other side of the longitudinal joint. Dowel steel is used for this purpose, the bars being about 5 ft. long and variously spaced but generally about 4 ft. apart. Recent observation points to the necessity for reducing the spacing of these dowel bars to about 2 ft.

METHODS OF REINFORCING

The utility of embedded steel in concrete road and pavement slabs has been satisfactorily established by numerous studies[1] of the subject and its use is almost universal, as was noted in a previous chapter. While the benefit of steel is proven beyond question, no method of calculating the exact amount or distribution of the steel in the slab has as yet appeared. Consequently there is some variation in the steel requirements of various specifications, as will be noted in the standard sections in Fig. 62.

Purpose of Reinforcement.—Reinforcement is used in concrete road pavements, not to add to the flexural strength but to transmit shear at cracks and joints and to prevent contraction cracks from opening to an extent that complicates the maintenance of the pavement. If cracks develop in such a manner as to form corners or edges in the interior portion of the slab, these are as much a source of weakness as they would be if they were at the edge. The reinforcement is presumed to provide dowels that will eliminate the possibility of independent corners or edges

[1] HOGENTOGLER, C. A., "Economic Value of Reinforcement in Concrete Roads," *Proc.* 5th Annual Meeting, Highway Research Board, Part III, 1925.

in the interior portion of the slab and free corners along the edge. This requires that the bars be close enough together to accomplish that purpose. When the slab is divided into strips 9 or 10 ft. wide by longitudinal joints, the probability of longitudinal cracks appearing between the longitudinal joints is remote and consequently the occurrence of corners except along the edges is not common. But transverse cracks are sure to develop and the longitudinal steel is intended to keep these from opening up and to dowel the two parts of the slab together.

The embedded steel may be the form of bars that are placed in the proper position in the concrete, or it may be in the form of mesh or fabric. The essential thing is to embed enough steel in the concrete to carry the shear across cracks and construction joints. One common method is to place bars along each edge and transversely across the slab about 6 ft. apart.

At construction and expansion joints, bars about 3 ft. long are placed about 4 ft. apart across the joint to dowel the two slabs together. At construction joints, one-half of the bar is coated with oil so that it will not bond to the concrete. At expansion joints some provision must be made to permit the bars to push into the slab when the expansion joint closes up.

If the longitudinal joint is used, the transverse bars extend across the joint so as to dowel the two halves of the pavement together.

Some engineers place the reinforcing material in the neutral plane of the slab, while others place it about 2 in. below the upper surface. Since it is not expected that the steel will particularly add to the flexural strength of the concrete, it seems to be immaterial in which place the steel is put, but as previously shown, it is most effective as reinforcement when placed near the surface. If steel fabric is used it is placed just as bars would be and short bars are used to dowel across the expansion and construction joints.

On the whole, it seems that there is considerable yet to be learned about the use of embedded steel in concrete roads and pavements, as it is very doubtful if the most efficient use of metal has as yet been worked out.

STORM-WATER FLUMES AND INLETS

When surface water is carried on the pavement slab to a convenient place for disposal, it may be led from the pavement

FIG. 63.—Types of flumes, inlets and wiers.

slab to an open ditch at the side of the road. To accomplish this the water may be taken into a tile underdrain through a typical storm-water inlet constructed at the edge of the slab, or it may be carried to the ditch in an open flume.

Where inlets and tile are used on rural highways the inlet offers a rather troublesome problem in design. It should be an axiom that no design be adopted that will obstruct the traffic lanes of the road slab and if constructed in the shoulder the size must be adequate to intercept the water, which sometimes requires a length of 15 ft. or more. The inlet is connected to a line of tile that generally discharges into the side ditch, or perhaps into a culvert. Typical inlets are shown in Fig. 63.

If flumes are employed they are generally wide and shallow and slope away from the edge of the pavement on a flat grade. If they are correctly designed and constructed it is possible to drive a vehicle across the flume without serious danger. If the water is being delivered from a pavement on a fill to a ditch beyond the toe of the slope, the flume should continue down the side slope of the embankment so as to eliminate erosion of the side slopes. Typical flumes are shown in Fig. 63.

INTEGRAL CURBS FOR CONCRETE PAVEMENTS

The concrete pavement may be constructed between separate curbs, but the more common practice is to construct the curb as a part of the pavement and integral therewith. Quite a variety of forms for the curb have been developed and there is no standard form.

In constructing the pavement, a side form is used that is of a height equal to the thickness of the pavement slab, and the pavement is finished as though no curb were to be used. A second side form is then set on top of the first and this forms the back of the integral curb. The form for the front face of the curb is held in place by clamps or brackets attached to the back form, and rests directly on the green concrete of the finished pavement. The area to be covered by the curb is roughened slightly and the concrete is placed and tamped lightly. The front form is then removed and the curb face and top finished with a long wooden float. Generally it is easier to get a finish if a small amount of mortar is spread over the face of the curb with the float.

Integral curbs have a very good appearance and are considerably cheaper than separate curbs. To avoid unsightly diagonal cracks in the curbs any expansion joints provided in the pavement should extend entirely through the integral curbs.

CONCRETE AGGREGATES

As information has accumulated with reference to the behavior of concrete slabs subjected to the wear of modern traffic in the United States, it has been necessary to revise completely the original conceptions with reference to the physical characteristics that should be possessed by the concrete aggregates.

The first consideration should be: What will concrete of the desired quality cost if it is prepared with any combination of proposed aggregates? That question can be answered after an analysis has been made in accordance with the more recent theories with reference to the design of concrete mixtures.[1]

The second consideration is the ability of the aggregates to withstand the disintegrating effects of climatic influences. If the road will be subjected to alternate freezing and thawing, the aggregates, especially the coarse material, must be capable of withstanding that action without disintegration. This may be determined by the accelerated test for soundness, checked by occasional freezing tests. If the road will not be subjected to freezing temperatures, it may be repeatedly saturated with water and the aggregate should be free of pieces that slake when wet. These soft pieces are usually in the nature of shale, clay balls, coal, and partial y disintegrated rocks. They are detected principally by visual inspection.

The third consideration is the ability of the concrete to withstand wear. This is only remotely a factor that varies with the character of the aggregates if the concrete has the requisite strength. On the basis of present knowledge of the subject, coarse aggregates of broken stone should be from rock with a French coefficient of wear of not less than 6. Gravel aggregates should show less than 18 per cent wear when tested by the Deval test (with shot in the rattler) for gravel. There is no accepted

[1] *Bulls.* 1–15, Structural Materials Research Laboratory, Lewis Institute, Chicago, Ill.

Crum, R. W., "Proportioning of Concrete," *Proc.* 13th Annual Meeting A. S. T. M., Vol. 27, Part II, p. 337, 1927.

test for the wear-resisting properties of sand and in general the wearing properties of sand will be satisfactory if it is suitable for making concrete of the desired strength. If coarse aggregates show up well when tested for hardness and toughness, that is, an indication that they will make strong concrete if other factors are satisfactory, but those tests have little relation to the ability of the resulting concrete to resist wear.

Broken Stone for Coarse Aggregate.—Broken limestone has been used for concrete roadways from the beginning and is entirely satisfactory if it will pass the Deval test with a French coefficient of at least 6, and is sound. Most limestones have been used to some extent for general concrete construction, and the question of their soundness has long since been determined by experience. Untried materials should be tested for soundness as well as for rate of wear.

Coarse aggregates that became coated with clay in the process of quarrying and crushing are objectionable because of the weakening effect of the coating of clay. Such materials should be avoided.

Crushed stone of any kind should be screened, with a view to eliminating the dust that results from the crushing operations. The harder types of broken stone, such as quartzite and the several varieties of trap and granite, are excellent coarse aggregates for concrete roadways, and where these varieties are available they are widely used because of the high quality of concrete produced with them. Material of this sort should be tested for uniformity and cleanness just as carefully as the limestones are.

Gravel Aggregates.—Pebbles screened from natural gravel, including crushed material obtained by reducing the larger stones in the deposits, are widely used for coarse aggregates. With material of this sort the question of uniformity must be investigated carefully because of the great variation in gravel deposits. Deleterious material such as shale, partially disintegrated pebbles, clay balls, and soft rocks are often encountered in gravel deposits. When using material of this sort one must not expect the impossible in the way of uniformity and soundness but, on the other hand, ordinary good practice requires that reasonable cleanness and uniformity be secured. Probably no reduction in the wearing properties of the pavement will result from 2 or 3 per cent of inferior material in the coarse aggregate,

and it is within the commercial possibilities to produce gravel aggregate of that degree of cleanness. It has sometimes been stated that the rounded pebbles would loosen in the roadway surface more easily than would angular particles of broken stone. This may exist as a tendency, but experience does not seem to indicate there being any likelihood of serious deterioration of the roadway surface from this cause.

Slag for Coarse Aggregate.—In recent years it has been proposed to use crushed blast-furnace slag for the coarse aggregate for concrete roadways, and both in the United States and in England a goodly amount of work has been completed in which this material was used. Like any new material, it has been slow to establish itself, but as the manufacturers have found proper methods of cooling and preparing the slag it is becoming recognized as a satisfactory coarse aggregate.[1]

Sandstone for Coarse Aggregate.—The fact that sandstone paving blocks have been fairly satisfactory in some states has led to the consideration of broken sandstone for coarse aggregate. Up to the present time little use has been made of this material for concrete surfaces, and until a sufficient amount of pavement has been placed to permit a proper study of the service value of the material, any construction in which it is employed must be looked upon as somewhat in the nature of an experiment. There seems to be no good reason, however, why the better grades of sandstone should not prove satisfactory for coarse aggregate.

Size of Coarse Aggregate.—No theoretical consideration is involved in the determination of the size of coarse aggregate. Probably the most satisfactory material is one that will pass a 2½-in. screen and that contains not to exceed 5 per cent of material that will pass a sieve having openings 0.185 in. square, and this is the standard coarse aggregate. In practice, available supplies of materials and the prices thereof determine the sizes that will be used. It has been shown by various investigators that good concrete can be made from a wide variety of aggregates and there is often opportunity to lower costs by using other than standard coarse aggregate. Reference to "Abrams Table of Proportions" in Chap. XXIII will indicate the wide diversity in the sizes of aggregates that may be safely employed in concrete for road purposes.

[1] "Use of Slag in Concrete Roads and Pavements," *Symposium* 11, National Slag Association, Cleveland, Ohio, 1928.

Fine Aggregate.—The standard fine aggregate is natural sand of a size passing a sieve having openings 0.185 in. square and containing not more than 5 per cent passing the standard 100-mesh sieve. Between these sizes the sand should be reasonably well graded. It should be so clean that not to exceed 2½ per cent of silt and clay will be removed by the usual test. Mortar composed of one part of cement and three parts of the sand should have a strength in tension and compression at least equal to that of mortar composed of the same cement and standard Ottawa sand made at the same consistency. Most of the really good sands produce mortar having a strength considerably greater than that produced by standard Ottawa sand.

As with coarse aggregates, the engineer is often compelled to use fine aggregates that are considerably less desirable than the sand described above, and this can be done successfully only when the inferior sands are shown by rigid test to have the desired strength-producing and wear-resisting properties.

Materials for Two-course Pavements.—In some localities coarse aggregate of a quality suitable for the wearing course is high-priced, while material that will make strong enough concrete is readily available at low prices. In such cases the two-course type of construction is used.

The sand and the coarse aggregate for the wearing surface would be of the same quality as those employed for a one-course pavement, but the lower course of the slab would be made of any material that would give concrete of the desired strength.

CONCRETE MIXTURES

The design of concrete road slabs is based on the estimated flexural strength of the concrete that it is proposed to use. The first consideration is the design of a mixture of the available aggregates, therefore, that will produce concrete of the desired flexural strength. During the season of 1928 the prevailing practice was to design concrete mixtures to give a flexural modulus of rupture of about 500 lb. per square inch when the concrete was 7 days old and had been cured under normal summer temperatures by the usual methods, ordinarily by covering with burlap and later with earth, and sprinkling.

It has not been the practice to specify a fixed proportion for the concrete mixture regardless of the combination of aggregates, but rather to provide a basis for adapting the mixture to the

aggregates actually received on each job. In fact, the mixture is varied slightly from hour to hour through the day on some jobs to compensate for variations in the aggregates actually received. Obviously, a proportion must be fixed before a batch of aggregates can be measured or weighed for mixing, but the exact proportion fixed for one batch may be held without change for hours of continuous operation or it may be changed at frequent intervals. Arbitrary proportions, such as 1–2–3, are rapidly being superseded by more scientific methods of proportioning.

If air-dry aggregates of normal properties are considered, the prevailing proportions used during 1928 would be 1 part cement, 2 parts fine aggregate, and 3 to 3½ parts coarse aggregate, with about 6 gal. of water per sack of cement used. But many designed mixes were used that were outside those proportions because of peculiarities of the aggregates employed.

In some of the smaller contracts, and in municipal work where the technicalities of the special assessment laws make it difficult to employ a variable mixture, fixed proportions are generally specified in paving contracts, and the two mixtures most widely employed are 1–2–3 and 1–2–3½. These will produce concrete of satisfactory strength if the aggregates are clean, sound, and well graded.

In some instances the designer does not have facilities for extensive investigations of the flexural strength of concrete prepared from the aggregates available in his vicinity and is therefore compelled to estimate the probable flexural strength of the mixtures he designs. The data available to him are mostly in terms of the compressive strength of the concrete. Therefore, it is often convenient to be able to predict flexural strength and tensile strength from the probable compressive strength. For this purpose it is safe to assume that at any age the ultimate tensile strength of concrete will be one-tenth the ultimate compressive strength of that age, and that the flexural modulus of rupture at any age will be one-fifth the ultimate compressive strength at that age. Such ratios should be used with caution in connection with mixtures that depart widely from the customary proportions for concrete for road slabs, but appear to hold fairly well in all comparative tests so far reported.

When the concrete is placed in two courses the concrete mixture for each course is designed with a view to securing equal strength of concrete in each course.

Measuring Materials.—The necessity for care in measuring concrete materials, including water, to insure that concrete of the predetermined quality is actually produced on the job, is being given increasing emphasis. There is always a tendency to use too much water in mixing the concrete because wet concrete is easier to handle than dry. It is highly important to restrict the quantity of mixing water to the minimum that will produce workable concrete. For concrete to be finished by hand-tamping methods the slump[1] should not exceed 2 in., and for concrete to be finished with a mechanical tamper the slump would not exceed 1 in.

CONSTRUCTION DETAILS

The construction of concrete road surfaces has been characterized by a continual evolution of new methods and new devices for lowering costs and increasing production. The discussion that follows covers the main operations and is intended to indicate the usual practice. Many variations in practice are to be observed and new schemes for performing minor operations will be noted on the work of progressive constructors.

Preparation of Subgrade.—The subgrade is the portion of the roadway upon which the concrete slab is placed, and since it is imperative to secure as nearly as practicable the slab thickness provided for by the plans, the subgrade is shaped with considerable care. After the rough grading has been completed, the side forms are set and are then available as guides in connection with the final grading. For this final grading a subgrading machine is used unless the soil is very hard, in which case hand tools must be used to dress down the high places left by the rough grading operations. The special shape required for slabs with thickened edges is secured by the use of hand tools. The accuracy of the subgrade is checked by a template which rests on the side forms.

During the final dressing of the subgrade it is repeatedly rolled to insure uniform compression and eliminate soft areas that would become depressions during the period when trucks use the subgrade in delivering materials to the mixer. Some constructors keep a light roller working on the subgrade continuously to prevent ruts or other uneven places from developing. As a final check on the accuracy of the subgrade, a heavy tem-

[1] See Chap. XXIII for a description of the slump test.

plate with an iron-shod cutting edge is drawn along the forms just behind the mixer to shave off any high areas that may have escaped notice up to that time.

Subgrades for wide pavements are shaped with a blade grader and finished by hand methods.

Dry subgrades are thoroughly sprinkled before the concrete is placed so that the soil will not draw water from the freshly placed concrete. Very porous soils that are dry may take so much water from the concrete that shrinkage cracks will form. If sprinkling the subgrade does not prevent the formation of these cracks, a layer of light roofing paper may be placed on the subgrade.[1]

Forms.—The forms placed at the sides of the slab to retain the green concrete are also required to carry the finishing machine or the strikeboard used for shaping the surface of the concrete. Since these are of considerable weight, it is important to use fairly rigid metal forms which are securely staked in position, properly adjusted to line and grade, and firmly bedded so that they will not be displaced by the operation of finishing the concrete. In municipal practice, wooden forms are still employed to a limited extent, and if they are to be satisfactory, they must be of 4-in. dressed plank and must be carefully staked and braced to line and grade.

Water Supply.—The water supply for concrete work may be obtained by connection to a municipal water supply, in which case the connection is made to the fire hydrants along the street, usually by means of hose. If a municipal water supply is utilized for rural highway construction a pipe line is laid from the city main along the route of the proposed improvement, with cocks at frequent intervals from which a hose is connected to the mixer.

In many cases the water supply for rural highway construction must be obtained from streams along the highway, and the pipe line is laid from these streams in the usual manner. At the source of supply a motor- or gasoline-engine-driven pump of the triplex variety is employed for furnishing the water supply. It is not uncommon to use duplicate water supply equipment so as to avoid a possible shut-down on account of pump difficulties. Pipe lines are laid on top of the ground with provisions at inter-

[1] CRUM, R. W., "Hair Cracks in Concrete Pavements," *Engineering and Contracting*, Vol. 64, No. 4, Oct. 7, 1925, p. 791.

vals for equalizing the pressure. The size of pipe varies from 2 to 4 in., depending upon the length of the line, but the tendency is toward a large size so as to prevent friction losses in the pipe that would interfere with the delivery of an adequate supply of water.

Proportioning Plants.—The proportioning plant consists of elevated bins to which the aggregates are delivered by means of cranes or bucket elevators. The aggregates are drawn from the overhead bin into the device for proportioning the several aggregates, and in the plants of more recent design the weight method is employed for proportioning. Proportioning plants are of many varieties and may be constructed of timber or may be portable plants fabricated of steel, to be set up on the job. It is customary to set up the proportioning plant at the railway siding where the aggregates are delivered, but in some instances these plants are set up at a local quarry or gravel plant.

The equipment required for measuring the aggregates for batching are incorporated in the plant in such a manner that the materials flow by gravity from the storage bins to the measuring device and also from the measuring device to the trucks. If the concrete is mixed at the proportioning plant the mixer is mounted in the plant at such an elevation that the materials flow by gravity from the storage bins to the measuring device, then to the mixer, and finally into the trucks.

The preferred method of measuring the materials for a batch is to weigh the aggregates and cement and to use volume measurement for the water. Some types of volumetric proportioning devices are used with a degree of satisfaction but weight proportioning is rapidly superseding other methods. One kind of volumetric proportioning device utilizes an inundation system for measuring the sand and is generally regarded as satisfactory.

Dry-batch Method Of Proportioning.—In the dry-batch methods of proportioning, the aggregates are weighed into the truck, the cement added, and the load hauled to the mixer, which is operated at the place where the concrete is being placed. The aggregates are dumped into the mixer, the water added, and the concrete, when mixed, deposited directly upon the subgrade. This method of handling aggregates is probably more widely used than any other.

Wet-batch Methods of Placing Concrete.—In the wet-batch method of placing concrete the aggregates are proportioned and

dumped directly into a mixer which is located at the proportioning plant. The concrete is there mixed, discharged into the transportation, and hauled as mixed concrete to the place where it is to be deposited. The loads are dumped upon the subgrade and finished in the usual manner. This method has been quite successfully employed on a number of jobs and is entirely satisfactory if the haul does not exceed about 45 minutes. It is particularly adaptable to those locations where it is difficult to provide an adequate water supply along the road.

Mixing the Concrete.—The mixers employed for pavement construction will produce about 1 cu. yd. of concrete per batch. The materials are dumped into the loading skip which is then hoisted so that the aggregates will slide into the mixing drum. The water is introduced along with the dry aggregates and the mixing continues for about 1 min. While investigations have shown that well-mixed concrete can be produced in about 40 sec., yet with all of the uncertainties involved in this operation it is deemed wise to continue the mixing for the period of 1 full minute.[1] Upon the completion of the mixing, the concrete is chuted or conveyed by bucket to the place where it is to be deposited on the subgrade. The mixer sets the pace for all of the construction operations and the whole organization is built around it, with a view to getting maximum production out of the mixer. The mixers now in use travel on the subgrade, generally on the crawler type of tread, and can therefore be used when the subgrade is slightly moist. Concrete placing cannot be carried on if the subgrade is very wet, because the hauling will disturb the subgrade to such an extent as to interfere with securing the proper thickness of slab.

Machine Finishing.—The first finishing operation is performed by means of a machine which strikes the concrete to the required cross-section, at the same time screeding it and working the surplus water out of it. The working element of the finishing machine consists of a heavy metal screed which rests on the side forms and oscillates transversely, at the same time moving forward along the forms at a slow rate. The operation is by means of a gasoline engine carried by the frame of the machine and the whole machine rides on the side forms on flanged wheels. Some

[1] HARRISON, J. L., "Effect of the Length of the Mixing Period on the Quality of Concrete Mixed in Standard Pavers," *Public Roads*, Vol. 9, No. 5, p. 93, July, 1928.

finishers have two screeds for striking the concrete and sometimes a belt for final finishing, all operated as a single unit. After the first trip over the surface with the finishing machine the screeds are raised, the machine moved back, and the second finishing is accomplished in exactly the same manner as the first. If the forms are rigid and set firmly to grade this machine will provide a smooth, gritty surface of excellent texture, but rarely will it produce a wholly satisfactory riding surface, and therefore a final finishing is carried out by longitudinal floating with a wooden float. These longitudinal floats consist of a 2 by 8-in. plank, about 12 ft. long, spiked to the edge of a second plank to form a T-shaped float, with plow handles attached to each end. This special float is operated by two men who stand on bridges placed across the concrete slab. They float the surface with a longitudinal movement, thus insuring that all cross ridges are worked out of the green concrete. After covering the width of the slab with the float, the bridges are moved forward along the side forms about half the length of the float and the process repeated. This is continued throughout the length of the slab.

Water Curing.—The most common method of curing concrete is to sprinkle it lightly as soon as the concrete has set sufficiently to permit the light spray being used without forming pits in the surface. This light sprinkling is continued until the concrete has set sufficiently to permit covering the surface with burlap. The burlap is placed on the concrete and kept wet until the concrete has hardened sufficiently to permit an earth covering. The earth covering is provided by shoveling onto the surface about 2 in. of loose earth from the shoulder. As soon as the earth is in place it is thoroughly wetted and is kept wet for a period of about 10 days.

In some cases the surface is cured by the method known as "ponding." Dikes of earth are placed across the concrete at intervals and the surface flooded so that the concrete is covered with 2 or 3 in. of water, and this is replenished as it evaporates or soaks away so that the concrete is kept covered for a period of about 10 days.

Calcium-chloride Curing.—Calcium chloride in flake or granular form is also used as a curing medium. As soon as the cement takes initial set the calcium chloride is sprinkled on the surface of the concrete in sufficient quantity to cover the entire surface with a thin layer and as the calcium chloride takes up

water, it melts down into a covering that seals the entire surface, keeping the surface moist and preventing the evaporation of water from the concrete. This method has been used quite widely and is satisfactory if care is taken to secure an even distribution of the calcium chloride.

Sometimes the calcium chloride is added to the mixing water in the proportion of about 2 lb. to the bag of cement that goes into the batch. When used in this way the calcium chloride retains sufficient water to keep the concrete moist during the curing period. It also has the faculty of accelerating the setting operation and the concrete therefore hardens much more rapidly during its early life when calcium chloride is added than it does in the same period when other methods of curing are employed.

Bituminous Coatings for Curing.—Bituminous coatings applied to the green concrete are also employed as a curing medium. The bituminous mixture in the form of a thin cut-back, or emulsion, is sprayed over the concrete while it is still green, thus sealing the surface so that water will not evaporate from the concrete. When the road is placed in service the thin layer of bituminous material gradually wears off the surface leaving the concrete with the ordinary texture and somewhat darkened color.

Sodium Silicate.—Some use has been made of sodium silicate as a curing medium for concrete surfaces. A solution is made in the proportion of one part water and three parts of sodium silicate, or it may be purchase in the correct mixture for application. About 1 lb. of sodium silicate is required to cure 1 sq. yd. of road surface. This solution is spread over the surface of the concrete as soon as the workmen can walk on the concrete without doing injury. It is generally advisable, especially so in hot weather, to cover the surface of the road with burlap until the silicate solution can be applied, but in very cool weather this is not necessary. The sodium silicate seals the surface of the concrete, thus preventing the evaporation of water from the concrete. If there is much rain on the road during the first few hours after the silicate is applied most of it will wash off the road and retreatment will be necessary. The silicate does not have to be removed or treated in any way before allowing traffic to use the road.

Finishing Methods for Wide Streets.—Streets that are so wide that the finishing machines cannot be used must of necessity

be hand-finished. For streets up to 30 ft. in width it is practicable to use a strikeboard for shaping the green concrete. This strikeboard rests on the sideform and is drawn along the form by laborers who employ a tamping and forward movement that strikes the surface and pushes the surplus concrete ahead. As soon as they have struck off the surface the concrete is smoothed with hand floats, usually long-handled ones, which are operated from the side of the pavement. Finishing at contraction and expansion joints must be carried out from a bridge or from planks that rest on the green concrete. Wide streets are often laid in strips, each of which is finished and cured before the next parallel strip is laid. This method is particularly advantageous for streets more than 30 ft. in width. Longitudinal joints are provided to separate the several strips that are laid.

Curing Period.—Concrete surfaces are opened to traffic as soon as the concrete has attained the flexural strength assumed in the design. This is determined by breaking test specimens fabricated from day to day from the concrete that is being placed and cured as the road slab is being cured. The specified strength is attained in 4 or 5 days in warm weather and in various longer periods in cool weather. In the absence of test specimens, the concrete is cured for about 2 weeks in normal summer weather, and in cool weather for a longer period, determined by the engineer.

Resurfacing Concrete Roads and Pavements.—If it becomes desirable to resurface a concrete road slab, a new concrete surface may be added or the old concrete slab may be utilized as a base for some other type of surface. The existing conditions will in each individual case indicate which is preferable.

There have been a number of concrete roads resurfaced with concrete and there seems to be no question as to the stability of the resulting structure. The old surface is cleaned of any accumulation of foreign material, but no attempt is made to provide a bond between the new concrete and the old. Potholes in the old slab are first filled with concrete to restore the contour of the old surface. The new surface is then placed and finished exactly as though it were an ordinary concrete pavement. The concrete is of the quality already discussed and the thickness is usually about 4 in., although surfaces as thin as 2 and 3 in. have been constructed successfully. Embedded steel in the form of mesh or bars is placed in the concrete, and if the

old surface was provided with expansion joints, such joints are placed in the new surface directly over the old ones. The concrete resurfacing is carried out in substantially the same manner as the construction of a new pavement as previously described and the finishing and curing operations are especially emphasized.

Problems

1. A specification provides that a concrete pavement is to be constructed of concrete mixed from standard aggregates in the proportions of 1 part cement, 2 parts sand, and 3 parts stone. The pavement is on a residence street that carries some through traffic. Design the pavement slab and draw the cross-section and plan, showing all dimensions and the arrangement of expansion joints, contraction joints, and reinforcing. Assume ordinary soil foundation.
2. In the construction of a concrete driveway to an apartment-house garage it is expected to use unscreened gravel weighing when air-dry 110 lb. per cubic foot, and containing 65 per cent of sand by weight. Design the driveway (single lane) and determine the mixture to use for the concrete. The soil foundation is dense clay.
3. Design a two-lane concrete pavement for a trunk highway to be laid on a sandy loam subgrade. The concrete is to be proportioned for a flexural modulus of rupture of 600 lb. per square inch at the age of 28 days. Draw the cross-section and a plan view to show the arrangement of reinforcing and joints.
4. A concrete road is being constructed by the dry-batch method, using one mixer. Prepare an outline to indicate the inspectors required and the duties of each.
5. Design an expansion joint for a 20-ft. concrete road.

CHAPTER XIII

VITRIFIED BRICK PAVEMENTS

The brick pavement is one of the older standard types in use in the United States, particularly for city streets. Its construction reached a high state of excellence at a time when horse-drawn traffic with its metal-tired wheels constituted the most severe test of pavement durability. When traffic shifted to the types of vehicles with rubber tires, with attendant greater load concentration, road builders clung tenaciously to the old standards of design and for a period the brick pavement lost standing in comparison with some of the other types. In recent years a serious attempt has been made to bring the design of the brick pavement into harmony with the requirements for durability under present-day traffic and to regain the lost prestige. It seems likely that this most excellent type will assume increasing importance as time passes.[1]

Some typical cross-sections for brick pavements are shown in Fig. 64. These illustrate the composition of the pavement, but the detailed dimensions are a matter of design that is dependent upon the traffic to be served in any specific location.

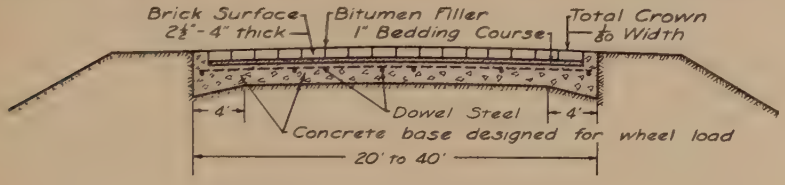
PAVING BRICK

Paving brick are manufactured from shale by what is known as the stiff-mud process. The shale is ground and puddled in a pug mill with enough water to produce a very stiff mud. The mud is forced through dies under considerable pressure and the column of clay that is extruded is cut into blocks of the desired size.

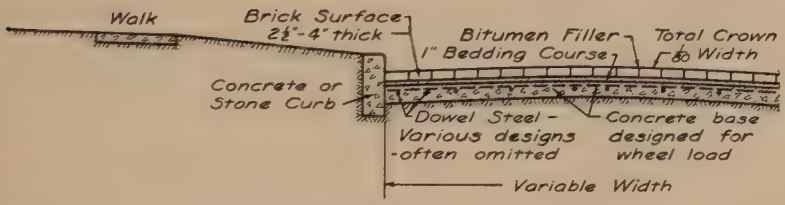
The process of manufacture of paving brick tends to introduce certain physical defects which have no particular significance unless they become so pronounced as to interfere with the proper laying of the brick or impair the strength. Certain of these defects are cause for rejection under most specifications.

[1] "Report of the Investigation of Paving and General Highway Conditions," by the Engineering Commission appointed by the National Paving Brick Manufacturers' Association, Washington, D. C., 1929.

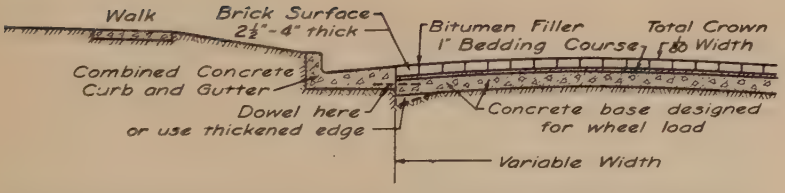
Laminations.—In the process of puddling the clay there is a tendency for layers to develop in the mass, and if the clay is not of the best quality these layers will not wholly weld together.



Two to Four Lane Highway Type



Street Pavement With Straight Curb



Street Pavement With Combined Concrete Curb and Gutter

FIG. 64.—Typical cross sections for brick roads and pavements.

This is evidenced by cleavage planes known as "laminations" which have no particular significance unless so marked that they indicate structural weakness in the brick.

Kiln Marks.—In the kilns, the brick are stacked in such a way that each brick will ordinarily have three good faces. The fourth face may be slightly distorted in the burning and may bear indentations from the brick upon which it rested, or that rested upon it. These kiln marks are not objectionable unless they are so pronounced that the brick will not lie evenly in the pavement.

Checks.—If the brick cool too rapidly they check because of contraction. Small checks are not uncommon but have no significance. Large checks are the cause for rejection.

KINDS OF PAVING BRICK

Several varieties and sizes of paving brick are produced, some of which are patented or trademarked and others of which are produced as stock types by a number of factories. There were at one time more than fifty sizes and varieties of brick being manufactured in the United States, but in recent years these have been reduced to the small number included in the present national standard sizes and types, which are generally called paving "blocks."

United States Standard Paving Bricks.—The following types and sizes of paving brick have been adopted by manufacturers and users as United States standards:

TABLE XII.—SIZES AND VARIETIES OF PAVING BRICK

Variety	Width, inches	Depth, inches	Length, inches
Plain wire cut (vertical-fiber lugless)	2½	4	8½
	3	4	8½
	3½	4	8½
Repressed lug brick and wire-cut lug brick (Dunn type)	4	3½	8½

Repressed Vitrified Brick.—The repressed brick is first molded slightly thicker than the finished brick is to be, and without spacing lugs. It is then repressed in a mold that puts raised lugs on one face of the brick. The lugs serve to separate uniformly the brick in the pavement so that the filler will flow freely into the joint between courses.

It is generally recognized that repressing has a tendency to weaken the structure of the brick, especially with some kinds of clay. Since practically all paving brick are manufactured by the stiff-mud process, incipient laminations are inevitable, and these may be made more pronounced by the repressing process.

Non-repressed Brick.—In order to eliminate any possible objectionable effect of repressing and to cheapen the process of manufacture, several types of brick are now made by processes which avoid repressing. The lugs for spacing the brick in the pavement are secured by various means, and the differences in the processes are chiefly differences in the method of securing the lugs.

Wire-cut Lugs.—In the Dunn process the column of clay is cut the long way of the brick, *i.e.*, the brick are "side cut," and the cutting wire is guided so that it cuts spacing lugs on the brick. The vertical faces of the brick are therefore the cut faces, and being rough afford a surface to which the filler adheres readily. It will also be noted that the edges of the brick which form the upper edge of the transverse joint between the rows are square.

Vertical-fiber Brick.—The term "vertical-fiber brick" is a trade designation for paving brick that are manufactured in such a way that the laminations, if any exist, will be perpendicular to the surface when the brick is laid in the pavement. This type of brick is wire cut, but instead of the wire-cut face being vertical in the pavement it is the top or wearing face of the brick. To secure lugs, ridges or beads are molded on one edge of the brick. These beads are vertical when the brick are laid and extend entirely across the brick. This type of brick also has a square edge at the joint between rows.

Still another type of non-repressed brick is provided with spacing lugs consisting of four raised knobs about ½ in. in diameter. These are molded on the brick as the clay comes through the dies, by a special device attached to the die.

Standard Lugless Brick.—Manufacturers have recently adopted a standard lugless paving brick. One end of the brick is slightly convex to serve as an end spacer. The brick may be laid either for a 4-in. wearing surface or for a 3-in. If laid for a 3-in. surface it is a "vertical-fiber-lugless" brick and it is generally used as such.

The kiln marks and other slight inequalities of the brick are assumed to prevent adjacent brick from being placed so closely

together that the filler cannot flow into the space between the brick. This type has been very widely used and seems to be wholly satisfactory.

Recently this type of brick has been manufactured to lay a wearing surface 2½ in. thick and there is every reason to expect this size to be generally used for locations where individual loads are not excessive.[1]

PHYSICAL CHARACTERISTICS OF PAVING BRICK

The suitability of brick for use in pavements is determined by laboratory tests to determine ability to resist wear, to carry loads, and to withstand the deteriorating influences of the elements, and by visual inspection to detect physical defects such as laminations, kiln marks, checks, and brick chipped or cracked in the handling.

Wearing Qualities.—The wearing properties of brick are determined by the rattler test described in Chap. XXIII. The limits placed on the loss during the rattler test will vary with the class of service demanded. The uniformity of the brick will be shown by the loss of individual brick, and it is therefore advisable in many instances to specify both the average loss of the ten bricks and the maximum permissible loss for an individual brick. The data in Table XIII indicate in a general way the limits that should be put on these two amounts.[2]

TABLE XIII.—LIMITS FOR RATTLER LOSS OF PAVING BRICK

Size, inches	Repressed brick, percentage loss		Wire-cut brick, percentage loss	
	Average	Maximum	Average	Maximum
3½ by 4 by 8½	22	24	23	25
3 by 4 by 8½	24	26	25	27
2½ by 4 by 8½	26	28	27	29

The quality of brick that should be used in any case is a matter that must be determined after a careful analysis of the traffic conditions and the foregoing table shows what is generally required for heavy-traffic pavements.

[1] TELLER, L. W., and J. R. PAULS, "Thin Brick Pavements Studied," *Public Roads*, Vol. 7, No. 7, p. 129, September, 1926.

[2] Specification of Ohio Highway Department, 1929, p. 140.

Effect of Absorption.—The absorption test indicates the density and, in a measure, the degree of vitrification of the brick. These facts are also shown by the rattler test, and the absorption test is rarely specified for paving brick. When both the average and maximum loss during the rattler test are specified, it is superfluous to include also the absorption test.

Cross-breaking Test.—The cross-breaking test is rarely specified for paving brick except when brick other than standard blocks are used. As a matter of experience, brick rarely fail by cross-breaking or crushing. The test is useful in judging the strength of the 2½-in. brick now coming into use. The test is particularly applicable to vertical fiber brick made from clays that have a tendency to laminate.

Regularity of Shape.—The paving block must be sufficiently regular in shape to lie evenly in the pavement and form a smooth surface. For that reason the brick must be reasonably straight and have one good face. Warped, twisted, or spalled brick cannot be used.

Kiln marks are found on many good brick, but if these are not too deep and the brick has one good face it may be used.

Checks that are serious enough to indicate careless burning, too rapid cooling, or poor material, are a cause for rejection of the brick.

Laminations, as has already been explained, are an indication of poor quality, and if serious are cause for rejection of the brick. This factor of itself rarely causes rejection but in conjunction with other defects in some doubtful cases may be the one that determines the rejection.

Summary of Requirements for Paving Blocks.—The following abstract indicates the usual requirement for quality of paving brick for heavy traffic conditions.[1]

a. Quality.—These brick shall be wire-cut-lug or plain wire-cut brick with lugs, thoroughly annealed, tough, durable, non-absorptive, and evenly burned. When broken they shall show a dense stone-like body, free from lime, air pockets, cracks or marked laminations. Kiln-marks shall not exceed one-eighth (⅛) of an inch in depth and the wearing surface shall show only slight kiln-marks. Only one kind of brick shall be used on a continuous section or roadway.

b. Size.—Wire-cut-lug brick or plain wire-cut brick with lugs shall be three and one-half (3½) inches in width, eight and one-half (8½)

[1] Specifications, Pennsylvania Highway Department, 1929, p. 133.

inches in length, and three or three and one-half (3 or 3½) inches in depth, as may be specified on the drawings. The brick shall be provided with not less than two (2) projections or lugs on one (1) side, which shall extend from the body of the brick not more than one-quarter (¼) nor less than one-eighth (⅛) of an inch.

Brick shall not vary from the above dimensions more than one-eighth (⅛) of an inch in width or depth, nor more than one-half (½) of an inch in length.

The brick shall have square edges and the ends of the brick shall have a bulge of at least one-sixteenth (1/16) of an inch. The name of the brick or manufacturer if formed on the brick, shall be made by means of recessed letters.

c. Resistance to Abrasion.—The average abrasion loss on any kiln, pile, carload, or other lot of brick shall be determined by the rattler test, and the brick shall be of uniform quality as hereinafter specified.

For brick three and one-half (3½) inches in depth, and of length and breadth previously specified, the abrasion loss shall not exceed twenty-six (26) per cent by weight; for brick three (3) inches in depth and of length and breadth previously specified, the abrasion loss shall not exceed twenty-six and five-tenths (26.5) per cent by weight.

FOUNDATION COURSES

While it is sometimes economical to employ some other material, the concrete base is the predominant type for the brick pavement as well as for many other kinds of pavements.

There has been much discussion of the question of the thickness required for the concrete foundation for the brick pavement, and of the quality of the concrete. The following is based on what appears at the present time to represent the best knowledge of the subject:

Concrete Base for Bituminous-filled Brick Surface.—It is assumed that the brick surface adds nothing to the flexural strength supplied by the concrete foundation. Since the concrete slab will have construction joints in it, and will crack more or less on account of temperature effects, the critical condition is reached when a load is placed over a corner formed by the intersection of two cracks, or a crack and the edge of the base. It is possible that the bricks themselves will span the crack and that under traffic loads in the average case the concrete must deflect alike on both sides of a crack. If that assumption is correct the formulas developed for concrete road slabs with embedded steel may be applied to the design of the base for a brick pavement.

It appears to be much better engineering, however, either to design the base by the formulas for plain concrete road slabs or to use steel in the base. The choice is a matter of cost to a large extent.

In general the concrete foundation slab for a brick pavement presents a design problem involving an estimate of the probable load and impact allowance, strength of the concrete that will be used in the slab, and whether edge loads are to be expected. There is evidence to indicate that dowel steel and expansion joints are desirable for the concrete slab that is to be used as a base course for a brick pavement.

Courtesy of R. L. Bell.

FIG. 65.—Special template for monolithic brick road construction.

Many thousands of square yards of brick pavement are in use where the plain concrete base is only 5 or 6 in. thick, and the concrete mixed in about the proportion 1–2½–5, and their stability can be explained only on the theory that the brick span the cracks and joints and thereby affect the deflection under wheel loads, and that these pavements have never carried a volume of present-day truck traffic.

It is well to recognize the fact that the trend of weight of traffic units is upward and that the base thickness should be liberal because of the probable long life of the wearing surface and the heavier loads that will be likely to use the pavement eventually.

Concrete Base for Grout-filled Brick Surface.—In this type of construction the brick surface certainly adds to the flexural strength afforded by the concrete base, especially if the mortar

bedding course is used. The exact allowance to make for the strength added by the wearing surface has not been determined, but from the information available it is safe to compute the thickness required for the base without considering the strengthening effect of the brick surface and then to subtract one-half the thickness of the brick surface. This rule seems to apply also to the monolithic type of brick pavement.

Materials for the Concrete.—The requirements for the cement and fine aggregate for use in the concrete base are identical with those imposed for the concrete pavement. The coarse aggregate will not be subjected to direct wear and only such requirements as to cleanness and soundness should be imposed as will insure concrete of the desired strength. The aggregate can be somewhat softer than would be permissible for use in a wearing course, but satisfactory coarse aggregates will usually have a French Coefficient greater than 5. There is a tendency to use unscreened gravel and poorly graded broken stone more freely for base courses than for wearing course concrete. This is permissible if economical in a particular location. In any case the mixtures should be carefully designed to produce concrete of the flexural strength assumed in designing the concrete base.

Macadam Base Foundation.—In locations where sand and cement are not readily available and consequently are high-priced, the base is sometimes constructed of water-bound macadam. This type of base can be used successfully if the traffic does not include any considerable number of loads in excess of 4 tons. Eight inches is the minimum thickness for such a base and the construction must be of the best to insure a stable pavement. The base is constructed in exactly the same manner as a water-bound macadam wearing course.

Bituminous Macadam Foundation.—Bituminous macadam is used to a limited extent for the base course and when properly constructed is satisfactory. If it is economical in any locality there is no reason why it should not be used. It is usually at least 8 in. thick and is constructed of the materials and in the manner prescribed for standard bituminous macadam of the hot-mixed type.

Brick Foundation.—The earlier brick pavements were built with a base course of No. 2 paving brick but this type of construction is now obsolete. There may be an occasional situation where this type of construction would serve, but in general it is

inadequate for the traffic on any highway that requires a brick pavement.

CURBS

Brick pavements for streets are designed with combined concrete curb-and-gutter, straight concrete curbs, or stone curbs, preferred in the order given. Stone curbs are rather infrequently used but the choice between the other types is largely a matter of personal preference. Some economy results from the use of the concrete curb-and-gutter because the gutter slab costs less per unit of area than the brick pavement. Brick rural highways are usually designed with a marginal curb of concrete which is integral with the concrete base.

BEDDING COURSES FOR THE BRICK

The bedding course affords a means of adjusting the brick so that the upper surfaces will form a smooth pavement, and serves as a means of equalizing possible unevenness in the concrete foundation.

The bricks will not all be of exactly the same depth, and some will have slight imperfections such as kiln marks or slightly warped or checked surfaces. These defective surfaces are placed on the bedding course when the brick are laid. In the operation of laying, there will be some unevenness due to lack of skill on the part of workmen. When the brick surface is rolled, all of these inequalities are removed, the brick being pressed into the bedding course until the upper surfaces conform to the desired contour of the pavement.

The bedding course should be thick enough to permit rolling the brick without breaking them, and a rather extensive study indicates that 1 in. of bedding material is about the practical minimum. On the other hand, it seems to add an unnecessary expense if the bedding course is made thicker than 1¼ in.

The mortar bedding course does not tend to reduce the amount of impact transmitted to the concrete base, but it appears that the sand bedding course does absorb some of the impact and the same is probably true of the mastic and granulated slag bedding courses.

Sand Bedding Course.—The sand bedding course consists of about 1 in. of fairly clean, moderately fine sand. There is a tendency for the sand to shift under the brick, due to the vibration from traffic, and for it to sift into cracks in the concrete base, thus allowing the brick surface to settle unevenly. If

water enters along car tracks or cracks in the pavement, that has a tendency to cause the sand to shift. These defects of the sand bedding course are of no great significance where traffic is moderate but may become serious when the traffic is dense and the individual loads heavy.

Mortar Bedding Course.—The mortar bedding course was developed to secure a supporting layer that would not shift under the brick. The mortar is composed of 1 part cement, and anywhere from 4 to 6 parts of sand. These are dry-mixed and spread on the base in a layer about 1 in. thick. After the brick have been rolled, the pavement is sprinkled and thus water is provided for hydrating the cement which, upon setting, affords a bedding course that is especially desirable on streets with heavy traffic and where there are car tracks on the street.

Bituminous-mastic Bedding Course.—The bituminous-mastic bedding course consists of sand to which is added about 6 per cent by weight of light tar or asphaltic oil.[1]

The materials are heated and mixed, usually in a portable mixing plant, and then used in exactly the same way as the mortar bedding course and for like conditions.

Granulated Slag and Screenings for Bedding Course.—Screenings obtained in the preparation of commercial crushed stone have been used for the bedding course under the brick, but difficulty is experienced in rolling the brick to a smooth surface because the screenings layer will not yield under the brick. For that reason this type of bedding course has never been widely adopted. Granulated slab which is prepared for the purpose has been used for the bedding course and is satisfactory. It is used in lieu of a sand bedding course.

FILLERS FOR BRICK PAVEMENTS

The filler serves to bind the brick together so that they will not be disturbed by traffic; supports the upper edge of the brick so as to reduce the abrasion, and closes up the surface so water and street liquids cannot penetrate to the bedding course. Bituminous materials or cement grout may be used for the filler.

The Grout Filler.[2]—The filler is composed of one part each of clean, sharp, fine sand and portland cement. The mixture, not

[1] See Chap. XVI for a description of these materials.

[2] The cement grout filler is seldom used any more, but a description is included since it has not been wholly discarded. The bituminous filler is much preferred for most locations.

exceeding one sack of the cement, together with a like amount of sand, is placed in a box and mixed dry until the mass assumes an even and unbroken shade. Water is then added, forming a liquid mixture of the consistency of thin cream.

The work of filling should be carried forward until an advance of 15 to 20 yd. has been made when the same force and appliance are turned back and cover the space in like manner, except that the mixture shall be slightly thicker for the second coat.

To avoid the possibility of thickening at any point the surface ahead of the sweepers and ahead of the mixture should be gently

Courtesy of Mr. Will P. Blair.

FIG. 66.—Applying grout filler to brick pavement.

sprinkled using a sprinkling can the head of which is perforated with small holes.

After the joints are thus filled flush with the top of the brick and sufficient time for hardening has elapsed so that the coating of sand will not absorb any moisture from the cement mixture, ½ in. of sand is spread over the whole surface, and in case the work is subjected to a hot summer sun, the sand should be sprinkled lightly for 2 or 3 days. The street should be kept closed for 10 days in warm weather, and for a longer time if the weather is cool.

Recently, a successful mechanical mixer for the grout filler has been perfected which considerably simplifies the mixing

operation. The mixer is drawn along on the brick surface after the rolling and delivers the grout to the brick through a swinging chute. The area of pavement under the mixer should be kept covered with a canvas to catch the drippings from the mixer.

Bituminous Fillers.—When a bituminous filler is used instead of a cement grout filler, the pavement is completed in the same manner as when the grout filler is used, up to the point where the filler is applied. Bituminous fillers must be poured into the joints at a temperature sufficient to insure adhesion to the brick. This varies with different classes of materials, but usually is about 400°F. for asphalt fillers and about 250°F. for pitch fillers.

Some specifications provide that the joints shall be filled without covering the surface of the brick. The device which is used for pouring the filler under such a specification consists of a cone-shaped vessel having at the point a cast-iron tip with an opening about ¼ in. in diameter. The pouring can is drawn along the crack between the rows of brick, the point resting in the crack. The opening in the point is controlled by means of a valve with a handle conveniently arranged so that the flow of the bituminous material can be adjusted. As the vessel is drawn along the bituminous material is allowed to flow out into the joint in sufficient quantity to fill it. A helper replenishes the supply in the pouring can from time to time so that the pouring goes on continually.

Squeegee Method.—The high labor cost of filling the joints by means of the pouring can has led to the general adoption of the less expensive squeegee method, which has practically superseded all other methods of filling the joints of brick pavements.

In the squeegee method, the hot filler is poured onto the surface from pails and then worked into the joints by means of long-handled squeegees. It is impossible to scrape all of the filler from the surface of the pavement by this method, but on the contrary, there remains a thin layer of filler on the surface. This layer will remain intact for several years and serves as a very satisfactory carpet coat. After the filler has been applied the surface is covered with a light dressing of sand to prevent the filler from adhering to the wheels of vehicles.

Quantity of Filler Required.—The quantity of filler required to fill the joints will vary with the size of the joint, which will depend upon the setters, but the average 4-in. brick surface will require about 12 lb. of filler per square yard of surface if filled by

the pouring method, and about 16 lb. if filled by the squeegee method. The 3-in. surface will require approximately three-fourths as much.

Quality of Bituminous Filler.—The following specifications provide a suitable filler to use by the squeegee method:

ASPHALT FILLER

The asphalt shall be homogeneous, free from water, and shall not foam when heated to 200°C. (392°F.) It shall meet the following requirements:

Specific gravity at 25°C	Not less than 0.980
Melting point	Not less than 80°C.
Penetration at 25°C., 100 g., 5 sec	30 to 45
Penetration at 0°C., 200 g., 60 sec	Not less than 20
Penetration at 46°C., 50 g., 5 sec	Not more than 100
Loss at 163°C., 5 hr	Not more than 1 per cent
Penetration of residue at 25°C., 100 g., 5 sec	Not less than 80 per cent of the original
Total bitumen (soluble in carbon disulphide)	Not less than 99 per cent
Organic matter insoluble in carbon disulphide	Not less than 0.7 per cent

Bituminous-mastic Filler.—The mastic employed for the joint filler consists of equal parts of a suitable bituminous material and fine sand. The materials are hot-mixed and the mixture is dumped on the brick surface and worked into the joints by means of squeegees.

This type of filler is especially adapted to locations where the pavement becomes very hot at certain seasons and where in consequence of steep grades the straight bituminous filler might flow from the joints. Any bituminous material that would be satisfactory for a carpet coat will serve for the mastic filler.

Expansion Joints.—Expansion joints are not required when the bituminous filler is used, but are generally employed for grout-filled brick pavements. The object of using the expansion joint is to take up the change in dimension of the grout-filled pavement following temperature changes. It is important on street pavements to provide for ample expansion along both curbs where the joints should not be less than ½ in. wide, for streets over 14 ft. wide, and not less than 1 in. for streets between 25 and 40 ft. wide.

Opinion differs as to the necessity of transverse joints. It seems to be well established that they may be omitted in regions where excessively high summer temperatures do not prevail, because expansion will not produce critical compression in the brick surface. Expansion crosswise of the pavement will move the curbs because they do not have sufficient support to withstand the pressure. Where summer temperatures are high, transverse expansion joints are used at intervals of between 50 and 100 ft.

Expansion joints are formed by a wooden strip set into the brick surface as the brick are laid. After the grout filler has hardened the wooden strips are removed and the joint filled with a straight asphalt filler or with a mastic.

There are several prepared joint fillers which consist of sheets of a bituminous material of the requisite width and thickness to fill the joints. This filler is set in place as the brick are laid.

BRICK RURAL HIGHWAYS

Design.—Brick rural highways are now called upon to carry loads that are the equal of those encountered in the cities, if the very few exceptional special loads that sometimes use city streets are disregarded, and the design must be based on heavy loads applied at the edge of the pavement. The principles of design that have been discussed in connection with city pavement are applicable to the rural highway if account is taken of the edge load to which the rural highway is subjected.

The concrete foundation is very generally employed and the marginal curbs, which are intended to retain the brick, are constructed integral with the concrete foundation. The marginal curbs are generally 6 in. wide and finished level with the brick surface, except on long grades where it is desired to retain the storm water on the pavement to reduce erosion. On such grades the cross-section is usually identical with that used for city streets except for the width. The bituminous filler is employed to fill the spaces between the brick and expansion joints are omitted.

The various operations involved in the construction are carried out very much as for city pavements, the requirements for materials are the same, and the necessity for careful workmanship equally imperative.

CONSTRUCTION METHODS

The construction operations in connection with brick pavements are organized with a view to securing maximum production with the plant available. The brick are hauled to the site and stacked outside the lines of the pavement as soon as the rough grading is completed. On city work the curb is next constructed followed in order by the construction of the concrete base, bedding course, brick course, and finally the usual cleaning up.

Earth Subgrade.—The earth foundation upon which the concrete foundation rests is known as the "subgrade or roadbed." After the pavement is completed, surface water will be cared for in pipe drains and will have little tendency to percolate to the subgrade. The pavement usually lies below the level of the parkings and lawns alongside, and underground water will be likely to percolate under the pavement base but the amount is generally insignificant. Porous soil and unfavorable topographical conditions may create a situation in which the subgrade will become water-saturated and unstable unless special precautions are taken to prevent it. The best precaution is to install suitable underground drainage. Sometimes storm-water sewers or sanitary sewers along the street will afford sufficient drainage, but in other instances additional tile drains must be laid. These are usually placed just back of the curb line and at a depth of 4 to 6 ft.

For a country brick road the drainage must be taken care of as faithfully as if the road were to have no hard surface and according to the principles discussed in Chap. III.

The subgrade is brought to the proper elevation and cross-section by excavating or filling as the case may be. If fills of less than 2 ft. are constructed they are built up in layers about 6 in. thick and each layer is rolled before the next is placed. For satisfactory results, the soil must be moist when it is rolled. Where cuts are made, it is advisable to plow within 2 or 3 in. of the subgrade and then roll to compress the subgrade to the proper elevation. The exact amount that the subgrade can be compressed by rolling varies with the type of soil and its condition, but it can readily be determined for each particular instance. A roller weighing 8 to 10 tons should be used for compacting the subgrade.

When finished, the surface of the subgrade should be true and smooth and so compact that the roller makes no perceptible

track upon it. Unevenness in the subgrade means inequalities in the thickness of the concrete base. Any high places in the subgrade may reduce the thickness of the base to such an extent as to reduce appreciably the load capacity of the pavement.

Placing Foundation Course.—When the concrete base is used it is constructed in a continuous operation for the full width of the pavement. For pavements up to 30 ft. wide some form of template can be used to shape the concrete to the proper form and thickness. For the wider pavements the concrete is shaped by means of shovels and lutes to elevations shown by pins driven in the subgrade. The concrete base should be of uniform texture, free of porous areas, and with no stones projecting out of the mortar.

Both the dry-batch and the wet-batch methods of construction are employed and the proportioning and mixing are rigidly controlled. Usually the minute mix is specified and the water limited to that which will produce a slump of 2 in. or less.

After the base concrete has been placed it is sprinkled daily for a week and the subsequent operations in connection with the construction should not begin for at least 10 days.

Placing the Bedding Course.—The bedding course material is spread on the base in a layer about ½ in. thicker than specified for the bedding course. Strips of wood of the thickness specified for the finished sand cushion are placed on the base near the curb and at the crown, and on top of these is placed a second set of strips ½ in. thick. The bedding course is struck off by dragging a screed along these strips, thus spreading the sand to the thickness of two strips combined. The screed is shaped to the proper cross-section and the cutting edge is shod with a metal plate. If the pavement does not exceed 25 ft. in width the screed may be constructed to span the entire width of the pavement, but for wider pavements it is better to span half the width.

After the bedding course has been struck off it is rolled thoroughly with a hand-operated roller about 30 in. long and weighing about 15 lb. per inch of length. The ½-in. wooden strips are then removed and the screed is drawn along the remaining strips and thus the well-packed sand is trimmed to exact thickness. The sand bedding course is most readily handled if it is in a moist condition, this being better than to have the sand either very wet or very dry.

Laying the Brick.—The brick are laid in straight rows at right angles to the center line except at intersections, where they are either laid parallel to the diagonals of the intersection or in the herringbone pattern. The end joints in each row are placed opposite the middle of the brick in the adjoining rows and part brick are used only in starting rows and making closures.

Lug brick are laid with the best face up and the lugs all in the same direction. After five or six rows have been placed they are closed up by driving with a maul. This is done to make the cross-joints as close as the lugs will permit. If lugless brick are used they are laid loosely and the courses are driven up just enough to keep them straight.

After the brick have been laid, the chips and spalls are swept off the surface, which is then inspected and all defective brick are replaced with good brick.

Rolling the Brick.—The brick are then rolled with a tandem roller weighing between 4 and 6 tons. The object of the rolling is to bring all the brick to a true surface, individual brick being adjusted by being pressed into the bedding course. If any are too low they are removed and a little material added to the bedding course. The rolling is started at the curb, the roller moving parallel to the curb and gradually working to the crown. The roller is then taken to the opposite side of the street and the operation repeated. After the first rolling, the surface is again inspected and all broken or spalled brick removed and replaced. The brick are again rolled, this time diagonally across the pavement, first in one direction and then in the other. Sometimes a final rolling parallel to the curbs is required. The brick cannot be rolled if the sand cushion is wet without forcing the sand up between the brick to an extent that will interfere with the penetration of the filler.

If the mortar bedding course has been used, the pavement is sprinkled after the rolling to furnish water for the cushion, provided the bituminous filler is to be used, but if the cement grout filler is to be used the sprinkling is done just before the grout is poured.

Monolithic Brick Pavements.[1]—The monolithic type of brick pavement is constructed by laying the brick-wearing surface

[1] BLACKBURN, W. T., "Brick Road Built Monolithic at Paris, Illinois," *Eng. Record*, Vol. 72, No. 2, p. 54, July 10, 1915.

directly on a freshly placed concrete base and rolling the brick to bed them in the concrete before it takes a set.

The general design and the requirements for materials are the same as for any other high-class brick pavement.[1] When constructed on a country road no marginal curb is used.

The subgrade is carefully prepared and thoroughly rolled and during the construction the vehicles used for hauling aggregates are kept on the side of the road as much as possible if the work is on a country road. The roller is kept at work on the subgrade, smoothing out the wheel tracks that are made by the trucks when they turn in on the subgrade to deliver concrete materials.

The concrete is mixed to a plastic consistency and struck off to the proper cross-section by means of a special templet which is a feature of the construction equipment that has already been developed for this particular type of pavement. It is shown in Fig. 65.

The templet consists of one I-beam crossbar and one channel crossbar, spaced about 2 ft. apart and supported on the steel side forms by means of rollers. The templet is drawn along the side forms by the mixer. The forward member of the templet cuts the concrete base $\frac{3}{16}$ in. below the finished grade, and dry mortar of one part cement and five parts sand is spread over the concrete ahead of the rear bar of the templet. This dry mortar is spread over the base by the rear part of the templet and the brick are laid directly thereon.

The setters place the brick carefully with the best side up and the lugs all in the same direction, and while the laying cannot proceed quite as rapidly as on the sand cushion, probably under favorable conditions a laborer can lay three-fourths as many per day as he would on a sand cushion.

The carriers who deliver the brick to the setters walk over the brick already laid and apparently do not disturb them, although as a precaution a 1 in. plank is laid over the brick where the carriers first step onto the newly laid surface. The bats are cut and set as fast as the courses are completed so that the surface is kept finished up close to the setters.

As fast as the laying is completed the surface is rolled with a hand roller about 30 in. in diameter and 30 in. long and having a weight of about 600 lb. The rolling irons out the little irreg-

[1] Specifications, Illinois Highway Department, 1928, p. 62.

ularities of the surface and beds the brick slightly in the dry mortar on the concrete base.

The surface is grouted in the manner described for the brick surface on a sand or mortar cushion.

It will benoted that the feature of this construction is that the brick are laid directly on the concrete base before the concrete hardens. A thin mortar bedding course is used merely to smooth the surface of the base.

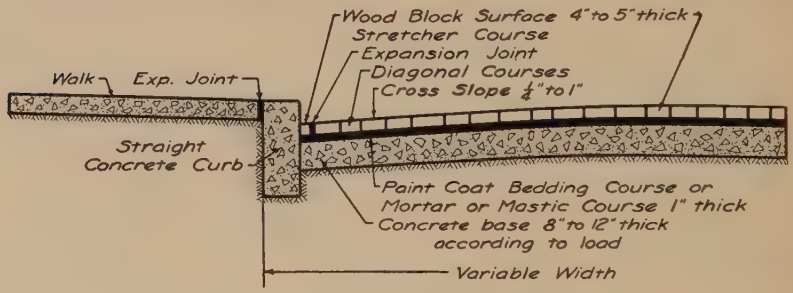
Problems

1. Design a bituminous-filled brick two-lane highway for a wheel load of 10,000 lb. The concrete in the base to be mixed in the proportions of 1 part cement, 2½ parts sand and 5 parts coarse aggregate and all of the aggregates to be of good quality. Estimate the quantity of brick, filler, bedding course and concrete required per mile of road. Submit also a drawing of the cross-section with all dimensions indicated.
2. A brick pavement 50 ft. wide is to be constructed between granite curbs. The wheel load is 12,000 lb. The base will be constructed of concrete having a flexural modulus of rupture of 700 lb. per square inch at an age of 28 days. Design the pavement and submit a drawing of the cross-section with all dimensions indicated.
3. A brick pavement is being laid on a curve of a radius of 300 ft. Draw a sketch showing the arrangement of the courses on the curve.
4. A brick pavement with poured asphalt filler is being constructed on a city street, the concrete base being placed by the wet-batch method. Brick laying was started as soon as the base had set sufficiently, so that all operations are under way simultaneously. Determine the number of inspectors required and specify the duties of each.

CHAPTER XIV

WOOD-BLOCK PAVEMENTS

Wood-block pavements have been used in Europe for many years and for at least 40 years in the United States. The earlier types were made from blocks sawed from round logs and laid as closely as their shape would permit. They were not treated with any kind of preservative and consequently the life was short and the pavement was rough, due to the shape of the blocks and the method of laying. Later, improvements were introduced that produced a pavement made up of blocks cut to a


Wood Block Surface 4" to 5" thick
Stretcher Course
Expansion Joint
Diagonal Courses
Cross Slope ¼" to 1"
Walk
Exp. Joint
Straight Concrete Curb
Paint Coat Bedding Course or Mortar or Mastic Course 1" thick
Concrete base 8" to 12" thick according to load
Variable Width

Cross Section for Wood Block Pavement

FIG. 67.

rectangular shape so as to lie closely and evenly in the pavement and the wood was impregnated with a suitable preservative. In consequence the more recent wood-block pavements have been much superior to the earlier ones.

Unfortunately, the wood-block pavement as constructed in the United States, developed two defects that have been quite troublesome. The more serious of these defects is slipperiness. As the blocks were used by traffic, the surface became very dense and hard. Oil drippings from motor vehicles, creosote that exuded from the blocks, and earthy material that accumulated on the surface, created a mixture that resulted in a very low coefficient of friction when the blocks were wet. The slipperiness can be eliminated by a light dressing of sand, but that is

a troublesome operation and must be repeated several times a year.

The other defect is a tendency for the surface to buckle when the blocks are wet. This can be avoided to a large extent by using the paint-coat bedding course and providing ample expansion joints.

Before these facts were realized, there had been a good many failures of wood-block pavements, and in addition, the high cost tended to discourage the use of this type of pavement. At present it is not widely adopted for new work. A typical cross-section for a wood-block pavement is shown in Fig. 67.

Design of Cross-section.—The wood-block pavement is invariably constructed with a concrete foundation, which is designed on the theory that the wood-block surface adds nothing to the flexural strength of the pavement. The concrete foundation may be designed with embedded steel or without, as may be the more economical.

The bedding course may be either lean-cement mortar or a thin paint coat of bituminous material.

The thickness of the wood-block surface is fixed by the severity of the traffic, but is generally 4 in. In special cases, block surfaces as thin as $2\frac{1}{2}$ in. are used. The cross-slope is held to the minimum consistent with drainage, because of the tendency for the surface to become slippery.

Curbs.—Straight concrete curbs are most widely used for the wood-block pavement, because it is a type of pavement most widely used for severe traffic conditions and much use is made of the pavement adjacent to the curbs. Occasionally the pavement has been provided with stone curbs. When the pavement is laid on medium-traffic streets, the combined concrete curb and gutter is sometimes employed.

SIZES AND KINDS OF BLOCKS

Kinds of Timber Used.—In the United States, Southern long-leaf pine, short-leaf pine, red gum, tamarack, Douglass fir, and Norway pine have all been used for the blocks. Probably three-fourths of the blocks laid, however, are made from southern long-leaf yellow pine. In this connection, the term long-leaf pine is used to designate quality rather than species, and short-leaf pine of sufficiently dense structure would be acceptable as well as the long-leaf pine. Abroad, short-leaf pine, white pine, redwood,

and fir are used principally although Australian hardwood is used to some extent.

Of the timber available in the United States, it is generally conceded that the Southern long-leaf yellow pine is the most durable. It is, however, hardwood and consequently the pavement in which it is used is likely to be more slippery than one constructed of some of the softwoods. Where traffic conditions are not severe and in parts of the country where the yellow pine is not available, other timber such as tamarack and fir are used successfully.

The essential characteristics of the timber are uniformity of texture and ability to resist wear, adaptability to the preservative treatment, and freedom from defects that will impair the life or wearing properties of the block pavement. Uniformity of texture is secured by specifying the minimum number of annual rings per radial inch in the block. Other defects are eliminated by inspection of the timber before it is cut into blocks and by inspection of the blocks during and after the laying.

Size of Blocks.—The depth of the block is varied to suit the traffic conditions, but in most of the pavements laid they have been either 3, 3½, or 4 in. deep, the last-named being used on the streets where traffic is dense and includes many heavy loads. The width of the block is not important so long as it is not greater than about 4 in., and blocks made by various manufacturers vary from 2½ to 4 in. in width. The length of the block is equal to the width of the plank from which it is cut, and consequently varies in any lot. It should never be less than 5 in. nor greater than about 10 or 12 in. If the block is too short, it will not sufficiently distribute the load that may come upon it, and if it is too long, it will split under heavy loads or not lie evenly in the pavement. All blocks used on any one contract should be of the same depth except that sufficient variation must be permitted to allow for the uncertainties of manufacture. Usually, for convenience in laying, all blocks used in any one contract should be of the same width except such variations as are incident to manufacture and this is limited to ⅛ in.

Quality of the Blocks.—The blocks must be free from defects such as large or loose knots, wind shakes, heart rot and pitch pockets. It is always desirable that the block be composed largely of heartwood and specifications usually require that a certain percentage (varying from 65 to 80 per cent) of the block

shall be heartwood. To preclude the use of coarse-grained, second-growth wood or short-leaf pine of poor quality, the number of annual growth rings per radial inch should be at least 6, and at no place on the face of the wooden block should the number of such rings be less than 4.

PRESERVATIVE TREATMENT

Character of Preservatives.—Wooden blocks, when used as a pavement surface, are laid with the grain vertical. The block in this position will wear for a long time if the wood does not decay. The cause of decay is fungus growth in the wood, and to prevent decay the blocks are impregnated with an oil which will prevent fungus growth. The material most commonly used for this purpose is coal-tar creosote.

The wood used for block pavements possesses another characteristic that is of some significance in connection with the preservation treatment. Untreated wood will absorb considerable quantities of moisture and in so doing will increase in size very materially. Treated blocks will absorb some water but by proper treatment the quantity can be reduced to an amount so small as to obviate serious trouble from swelling. Excessive absorption of water has caused considerable trouble due to the difficulty of taking care of expansion, especially on wide streets. Recent practice is to impregnate the blocks in a manner and with a material intended both to preserve and waterproof the wood. This is accomplished by using a mixture of creosote and tar.

Creosote Oil.—The preservative employed for wooden blocks is creosote oil, a coal-tar distillate, or a mixture of creosote oil and tar. Pure creosote is a distillate of coal-tar and its properties are shown in Fig. 68.[1]

Pure creosote, therefore, consists of varying percentages of the four groups of compounds indicated in the above diagram. Of these compounds the phenols are highly antiseptic and it is desirable that there be sufficient of these compounds mixed with the creosote to insure preservation. The naphthalenes are also antiseptic but also volatile at air temperature and will gradually leave the block by evaporation during the first years of the life of the pavement. The anthracenes are not as highly antiseptic as the phenols, but are much less volatile and are insoluble in

[1] Weiss, "The Preservation of Structural Timber," McGraw-Hill Book Company, Inc., p. 80.

water, while the phenols are soluble in water. It is generally believed that the creosote oil used for paving blocks should contain a considerable proportion of the anthracenes. The specific gravity of a pure creosote oil obtained by the distillation of tar will be from 1.03 to 1.08 at 25°C. Generally speaking, the higher the specific gravity the greater the proportion of the anthracenes in the creosote oil.

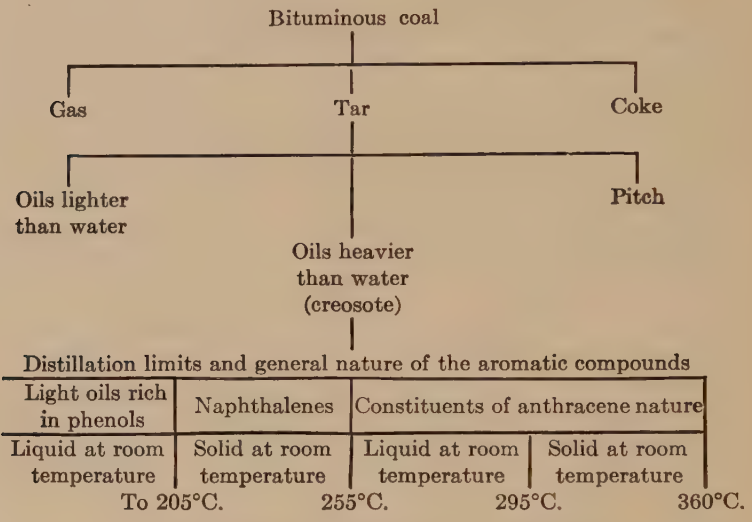


FIG. 68.—Source and composition of creosote oil.

Mixtures of Tar and Creosote.—The commercial creosote oil employed for the preservation of wood-paving blocks frequently has a specific gravity greater than 1.08 and sometimes as great as 1.14. Such an oil is a mixture of pure creosote and tar. It is contended that an oil of this character contains sufficient pure creosote to preserve the blocks and that the admixture of tar serves to increase the waterproofing properties of the oil. This is true if the percentage of tar does not run too high. It is known, however, that the presence of tar in the oil tends to increase the difficulties due to the blocks bleeding and that the presence of appreciable quantities of free carbon (soot) in the creosote oil is particularly objectionable.

CREOSOTE OIL SPECIFICATIONS

Two types of creosote oil are in general use for the preservative treatment of wooden paving blocks. One kind of preservative

is known as *coal-tar paving oil* and consists of a mixture of a distillate of coal tar with coal-gas tar, or of coke-oven tar. The other kind is known as *coal-tar distillate oil* and is a straight distillate of coal tar. The coal-tar paving oil has been used to a much greater extent than the coal-tar distillate oil because it is cheaper and is thought by many engineers to be entirely adequate for the purpose. Some cities, however require the use of the coal-tar distillate oil in spite of its greater cost because the blocks are cleaner and perhaps less likely to bleed badly than if the heavier oil is employed. The specifications for the two oils are as follows:

Coal-tar Paving Oil.[1]—The oil shall be a coal-tar product of which at least 65 per cent shall be a d tillate of coal-gas tar or coke-oven tar, and the remainder shall be refined or filtered coal-gas tar or coke-oven tar. It shall comply with the following requirements:

1. It shall not contain more than 3 per cent of water.
2. It shall not contain more than 3 per cent of matter insoluble in benzol.
3. The specific gravity of the oil at 38, compared with water at 15.5°C., shall be not less than 1.07 or more than 1.14.
4. The distillate, based on water-free oil, shall be within the following limits:

Up to 210°C., not more than 5 per cent.

Up to 235°C., not more than 25 per cent.

5. The specific gravity of the fraction between 235 and 315°C. shall be not less than 1.03 at 38, compared with water at 15.5°C.

The specific gravity of the fraction between 315 and 335°C. shall be not less than 1.10 at 38, compared with water at 15.5°C.

6. The residue above 355°C., if it exceeds 35 per cent, shall have a float test of not more than 80 sec. at 70°C.
7. The oil shall yield not more than 10 per cent coke residue.
8. The foregoing tests shall be made in accordance with the standard methods of the American Wood Preservers' Association.

Coal-tar Distillate Oil.[2]—The oil shall be a distillate of coal-gas tar or coke-oven tar, and shall comply with the following requirements:

1. It shall not contain more than 3 per cent of water.
2. It shall not contain more than 0.5 per cent of matter insoluble in benzol.
3. The specific gravity of the oil at 38, compared with water at 15.5°C., shall be not less than 1.06.

[1] Specification of the American Wood Preservers' Association, 1928.

[2] Specification of the American Wood Preservers' Association, 1928.

4. The distillate, based on water-free oil, shall be within the following limits:

Up to 210°C., not more than 5 per cent.

Up to 235°C., not more than 15 per cent.

5. The specific gravity of the fraction between 235 and 315°C. shall be not less than 1.03 at 38, compared with water at 1.55°C.

6. The residue above 355°C., if it exceeds 10 per cent, shall have a float test of not more than 50 sec. at 70°C.

7. The oil shall yield not more than 2 per cent coke residue.

8. The foregoing tests shall be made in accordance with the standard methods of the American Wood Preservers' Association.

There has been much discussion as to the relative merits of the light and heavy oils for the treatment of wood block, and exact data on the subject are lacking. The comparisons given in Table XIV are apparently well established:

TABLE XIV.—COMPARISON OF LIGHT AND HEAVY OILS FOR WOOD-BLOCK PRESERVATION

Heavy	Light
(*a*) Cheaper than the light oil	(*a*) More expensive than heavy oil
(*b*) A little better for waterproofing than the light oil	(*b*) Has better preservative properties than heavy oil
(*c*) Will probably preserve the blocks until they wear out	(*c*) Bleeds less than the heavy oil
(*d*) Contributes to bleeding	(*d*) Not quite as good a waterproofing material as the heavy oil
(*e*) Does not volatilize readily	(*e*) Volatilizes more readily than the heavy oil
(*f*) Contains little material soluble in water	(*f*) Contains more water-soluble portions than the heavy oil

Some attempts have been made to employ products of water-gas tar and of petroleum for wood preservation, but the use of these materials is as yet in the experimental stage and is not common practice.

Quantity of Preservative.—Experiments have demonstrated that for proper preservation of the blocks it is probably unnecessary to use to exceed 10 lb. of creosote oil per cubic foot of timber, but that for securing the necessary degree of waterproofing at least 16 lb. per cubic foot must be used, and it seems to be established that little benefit is obtained from the use of more than 16 lb. per cubic foot of timber. Practice in the United States is to treat with quantities varying from 12 to 20 lb. of creosote oil

per cubic foot of timber, while in many cases a much less quantity is used for the blocks laid in European cities.

Sometimes, when blocks are to be used for streets on which the traffic is very heavy, they are treated by merely dipping in hot tar. The amount of preservative thus absorbed is sufficient to preserve the blocks for the length of time that they can be expected to wear under the traffic conditions.

Bleeding.—Complaints are often made that creosoted block pavements become sticky in warm weather, the tar exuding from the blocks and sticking to the shoes of pedestrians, soiling clothes and being carried into stores and residences, and becoming a general nuisance. The causes of bleeding are several:[1]

1. The use of a tar and creosote mixture containing too much tar. Such an oil does not penetrate the blocks as thoroughly as do the lighter oils and the carbon in the tar has a tendency to lodge in the outer fibers of the block. When the oil in the block warms up and increases in volume the exudation brings with it the carbon. The heavy and sticky mixture of tar and carbon adheres to everything coming into contact with it. For these reasons specifications frequently limit the amount of free carbon in the oil to 1 per cent. In the past as much as 4 per cent has been permitted.

2. The use of too much oil. If the treatment is in excess of 16 lb. per cubic foot, it is inevitable that some bleeding will occur and treatments of 20 lb. per cubic foot or more are sure to bleed excessively.

3. Improper seasoning and treatment of the blocks. Artificial seasoning and the preliminary and final vacuum are thought to be advisable as reducing the amount of bleeding. The impregnation should be complete—not merely in the outer part of the block.

4. Insufficient provision for expansion of block in the pavement. If the block cannot increase in size when it swells, the effect will be to squeeze out the creosote.

5. The use of a filler soluble in creosote oil. Such a filler will soften up in time and exude at the joints. If too much filler is used the trouble is aggravated.

The preventive for bleeding then is to use not to exceed a 16-lb. treatment, to use pure creosote or creosote in which there is but

[1] Weiss, "The Preservation of Structural Timber," McGraw-Hill Book Company, Inc., p. 201.

little tar, either to treat green timber or to steam season the timber, and to use a filler not soluble in creosote and to provide ample expansion joints.

The cure for bleeding is to keep the pavement surface covered with torpedo sand until the bleeding stops.

MANUFACTURE OF THE BLOCKS

Cutting of Blocks.—The planks from which the blocks are to be manufactured are sawed with a thickness equal to the width desired in the finished block, which is from 2½ to 4 in. The planks are run through the planer to size them so that all blocks will be of the same width. A plank that is unusually dense, is wet, or is filled with pitch, will come through a little thicker than one that is dry or soft, so that some slight variations in thickness of plank, and, consequently, width of block is unavoidable in the process of manufacturing. The planks are inspected and any sections that contain inferior wood are cut out and rejected. The good portions of the planks are cut into lengths varying with the number of saws in the cutting machine. The cutting machine generally consists of a gang of saws that will cut a number of blocks at one time. From the cutter the blocks are delivered into iron racks in which they are piled loosely. The racks when filled are run into the treating cylinders which are usually about 8 ft. in diameter but of various lengths. Most of the treating cylinders will contain ten or more racks of blocks.

Seasoning and Treating.—When the blocks have been put into the cylinder it is closed tightly and the blocks are steamed to soften the pitch and resinous material. The steaming process to be of the greatest benefit must continue for at least 5 hr., although frequently a shorter period of steaming is specified. After the steaming process the cylinder is subjected to a vacuum which is intended to draw out from the blocks the moisture and some of the pitch and resinous material. All water that may have come out into the cylinder is pumped off and, after the vacuum has continued until the blocks are dry, the creosote oil is introduced into the cylinder and pressure applied until the proper quantity of oil has been forced into the blocks. The pressure permitted is generally limited to 200 lb. per square inch and often a less pressure is effective. The pressure must continue for about 3 hr. to insure thorough impregnation. When the proper impregnation has been secured, the excess oil is pumped

away and the blocks are allowed to drain for about 30 min. before being removed from the cylinder. It is also recommended that a final vacuum be drawn and held for about 30 min. to dry the blocks, but this practice is not general.

Inspection of Blocks.—The timber is inspected before it is cut into blocks and most of the defective material thus eliminated. The blocks can be weighed before they are placed in the creosoting cylinder and can be weighed again after coming out and thus the quantity of creosote injected can be computed. A slight error exists due to the fact that some moisture is extracted from the blocks during creosoting, but probably this is a small amount. A more reliable way of determining the amount of creosote injected is to observe the gage readings on the tanks before and after the creosoting treatment. Knowing the temperature of the creosote during treatment and in the tanks, the quantity injected can be computed. After the blocks are laid in the pavement they are again inspected and those that are checked or that contain large knots or other defects are removed and turned over or are replaced by good blocks.

BEDDING COURSES

Several methods of bedding the blocks are employed, of which the most common in the United States has been a sand bedding course similar in character to that which is used for the brick pavement and constructed in the same manner. Experience with the sand bedding course has not been entirely satisfactory because it has been prone to wash from under the blocks or to shift when dry, allowing the pavement to become uneven. This is particularly noticeable on streets carrying car lines, the jar of the cars being sufficient to loosen the blocks along the track and afford an opening for water.

Mortar Bedding Course.—The deficiencies of the sand bedding course led to the adoption of the mortar bedding course which has been described in connection with the brick pavement, and it is much superior to sand for wood-block pavements.

Paint-coat Bedding Course.—In other instances, a thick coating of tar is mopped on the concrete foundation and covered lightly with sand and the blocks are laid on the mastic thus produced. When the blocks are laid in this manner the concrete foundation must be finished with the surface as true to shape as that of the finished pavement and with a troweled mortar surface.

This method is used extensively abroad and is coming into use in the United States, and undoubtedly is one of the very best methods for laying this type of pavement.

A slight modification of the above method is found where one face of the block is dipped in tar just before it is placed on top of the concrete foundation which has previously been coated with a thin layer of sand. In other instances the concrete foundation is coated with tar and the blocks laid directly thereon without the sand coating being introduced.

FILLER FOR WOOD-BLOCK PAVEMENTS

The filler may be sand, asphalt, or tar, but probably a bituminous filler is more often used than any other.

The tar filler must be used sparingly on account of the tendency for it to soften with the creosote from the blocks and to bleed badly.

Where the sand filler is used, it is assumed that the sand becomes mixed with a considerable amount of tar and creosote from the blocks so as to form a mastic in the joint. Probably this happens to a considerable extent and if the blocks are placed on a heavy-traffic street, such a filler will be satisfactory because traffic will quickly close the joints between the blocks by cushioning down the fibers of the wood.

The asphaltic filler must be very hot when poured so as to pentrate the joints and care must be taken not to use an excess. Bituminous fillers are usually applied to the surface very hot and spread with a fiber broom or squeegee so as to fill the joints. The surface will also be coated and must therefore be covered with torpedo sand or stone chips. This coating does not adhere well to the blocks and will eventually scale off.

Method of Laying.—The blocks are laid in regular rows either at right angles to the curb or an angle of 65 deg. therewith, the latter probably being the more common method. When the courses are run diagonally it is assumed that no transverse expansion joints will be required, the blocks carrying the expansion to the curb in both directions. This has not proven to work out on streets more than 50 ft. wide, but is satisfactory for the narrower streets. Since the blocks usually have no lugs for spacing them in the pavement, it is possible to lay them too close together and thereby increase the difficulties caused by expansion. The blocks should be laid loosely, especially if they are

dry when laid. Some engineers advocate thoroughly wetting the piles of blocks some hours before it is desired to use them. Other engineers use a narrow strip of corrugated paper (such as is employed in packing fragile merchandise) between rows to space the block.

Expansion Joints.—If the blocks are laid diagonally, expansion joints are placed along the curbs, the width being 1 to 1½ in. It is customary to lay two or three stretcher courses next the curb and to provide the expansion joint between the row next the curb and the curbstones. If the combined curb and gutter is employed, no longitudinal rows are laid but the expansion joint is provided next the edge of the gutter slab. If the blocks are laid in rows perpendicular to the curbs, transverse joints ¾ in. wide are provided every 50 ft. These joints are filled either with bituminous cement, prepared expansion joint fillers, or bituminous mastic.

After the blocks have been laid they are rolled with a tandem roller weighing about 4 tons and in exactly the same manner that a brick pavement would be rolled. As in the case of brick pavement, the blocks are inspected before and after rolling, and all split or otherwise defective ones are removed and replaced with good blocks.

Characteristics.—The wood-block pavement is adapted to any volume of traffic and is exceedingly durable even under the heaviest traffic. It is smooth, resilient, and quiet but its one undesirable characteristic is its slipperiness. It is not suitable for grades in excess of about 4 per cent and if subjected to heavy horse-drawn traffic should not be used where the grade exceeds 2 per cent. The slipperiness can be overcome to a large extent if the pavement is sanded at the proper time. Some difficulty is encountered from expansion due to the wood swelling when wet, but this is eliminated by the use of suitable expansion joints and by avoiding laying the blocks too closely.

Problem

1. Write a specification for yellow-pine paving blocks to be used under very heavy traffic. Do not include the creosote treatment.
2. A specification for creosote oil provides that the free carbon (matter insoluble in chloroform) shall not exceed 4 per cent. The creosote is made up by mixing refined tar that contains 18 per cent of free carbon and has a specific gravity of 1.20 at standard temperature, with straight distillate oil having a specific gravity at standard temperature of 1.03.

What percentage of tar will be used in the mixture and what will be the specific gravity of the mixture?

3. Design a wood-block floor to be used in a structural steel fabricating shop where loads up to 5 tons on four steel wheels may be expected. Specify the strength of the concrete foundation and the preservative treatment of the wood blocks.

EXAMPLE OF GOOD PRACTICE

Recent Practice in Laying Wood-blocks[1]

The wood principally used has been long-leaf (yellow) Southern pine, which from experience has been found to give excellent results. Most specifications now, however, admit Norway pine and tamarac and white birch as a result of experimental pavements laid in Minneapolis, which showed the suitability of these woods. No doubt other species of wood make satisfactory pavements, but on account of the incomplete knowledge of their value city engineers, as a rule, prefer a wood that has proved satisfactory.

The blocks are from 3 to 4 in. wide and vary in depth from 3 to 4½ in., with a length of from 5 to 10 in. As for all timber specifications, the blocks should be sound, free from large or loose knots, shakes, wormholes and other similar defects. As to the proportion of sap and heartwood, the present specifications are not very rigid, as experience has shown that treated blocks having both sapwood and heartwood do not vary in their wearing qualities.

The preservative used is a creosote oil having a specific gravity of from 1.08 to 1.14, containing a percentage of tar, free from carbon. Coal-tar oils are used in preference to water-gas creosote, as sufficient experiments have not yet been carried out with the water-gas creosote to determine its relative value.

The writer has been corresponding with a number of city engineers with a view of obtaining opinion as to the most satisfactory amount of treatment required per cubic foot of block, according to the experience of each city, and in replies from 20 cities in the United States has ascertained that 6 of these cities use 16 lb., 2 of them 18 lb., and 12 of them 20 lb., depending to some extent on local conditions.

[1] Macallum, Andrew F., City Engineer, Hamilton, Ontario. Read at Canadian and International Good Roads Convention, Toronto.

Laying the Pavement.—The base for wood-block pavements should be of concrete, from 5 to 6 in. deep, having the crown parallel to the finished crown on the blocks. An uneven or irregular base is detrimental to any pavement, as it is liable to cause a depression in the surface to hold water, which the repeated impacts of wagon wheels is certain to increase, giving an uneven surface. Upon this concrete base is placed either a sand or a mortar cushion. This cushion is usually 1 in. deep, and has its surface struck by templates to a surface parallel to the contour of the finished pavement. Where sand is used, the sand is such that it will all pass through a ¼-in. screen, besides being clean. If a mortar cushion be used, some engineers use a proportion of 1 of cement to 3 of clean sand, to which sufficient water is added to insure the proper setting of the cement. Other engineers obtain good results by mixing and placing the cement and sand dry. This custom is simply a means of securing a uniform surface for the blocks to rest upon and distribute the load. Alongside or between street-car tracks, however, or on grades, sand cushions are apt to become uneven or flow, caused by the vibration of the rails, or by water getting in alongside the rails, so that under these circumstances a concrete cushion should be used. Away from the car tracks the question of whether a sand or mortar cushion should be used is a matter of opinion. Sand gives a better cushioning effect and the blocks do not have to be rolled so soon after laying as when a mortar cushion is used.

English and French practice does away with this cushion altogether, but the concrete base is finished off as smooth as a concrete sidewalk and to the exact contour of the surface of the pavement. This extra care and workmanship obtain results that are excellent, inasmuch as the finished surface of the blocks has no depression, and consequently the wheels cause no impacts.

In most cities it is not possible to lay the blocks shortly after coming out of the treating plant, and the hot sun and wind during shipment and before laying is apt to check the blocks and cause oil to exude. The blocks should be piled closely when delivered on the street and sprinkled before laying.

Generally, the blocks are laid at right angles with the curbs, with an expansion joint at each curb of from ¾ to 1½ in., according to the width of the pavement. Alongside the curbs three rows of block are laid parallel to the curbs, with the expansion joint next to the curb. Placing a longitudinal row of blocks,

with an expansion joint on each side is sometimes done, but is not good practice, as the single row of blocks between the joints will almost certainly rise up about the level of the adjoining pavement as the joints close up. Cross expansion joints have been used also by the writer when the treated block used had been piled on a street for several months, but for fresh blocks, properly treated, they are not necessary on streets of heavy traffic. On streets of light traffic, however, there should be cross expansion joints, placed from 30 to 50 ft. apart and having a width of about $\frac{3}{4}$ in. It is hardly necessary to say that the blocks should be laid with the grain vertical and having the joints in adjacent rows broken by a lap of about 2 in. The blocks should be laid neither too loose nor too tight, so that a block can be raised without disturbing the surrounding blocks, or $\frac{1}{8}$ in. apart. After the pavement is laid it should be rolled thoroughly with a roller varying from 3 to 5 tons until a perfect surface has been secured, with no depressions and the blocks firmly in place. There should be no difficulty in this, as the usual specifications for blocks allow of a variation of but $\frac{1}{16}$ in. in depth, so that if the foundation and cushion have been properly laid there is usually very little trouble about depth of the blocks.

Alongside street-railway tracks and about manholes special care should be taken in laying the blocks. It is usual in such cases to thicken the cushion so that the blocks shall be about $\frac{1}{4}$ in. above the wearing surface of the rail or cover, and in a very short time the traffic will rub these blocks down to the level of the rail. Alongside rails, to prevent water flowing down and under the blocks, two methods are used: One is to place a specially cut creosoted plank under the rail to give a vertical surface against which the blocks are paved; and the second and usual method is to plaster the web with a rich mixture of sand and cement to the width of the rail-head, and the blocks are then laid against this. As with other pavements it has been found that the girder lip-rail is more satisfactory than the ordinary tee-rail, unfortunately in use in most towns, for the permanence of the block on the inside or gage side of the rail. Incidentally, it may be said that no pavement will be satisfactory alongside a street-railway track if the rails lack sufficient weight, stiffness, and foundation to prevent movement, especially at the joints.

There is diversity of opinion among engineers as to the best joint filler to be used. The American Society of Municipal

Improvements recommends a suitable bituminous filler when the blocks are laid upon a sand cushion and a sand filler when laid on a mortar cushion. It is claimed for the bituminous filler, which fills the joints between the blocks two-thirds their depth (the remaining depth filled with sand), that it makes an absolutely waterproof pavement, and that it eliminates all expansion difficulties, as each block is surrounded with an individual expansion joint. Unless the filler is a suitable asphaltic cement, with a high melting point and low penetration, there is apt to be a sticky surplus left on the surface. This filler will cost about 15 cts. a square yard more than a sand filler.

A cement grout filler has been used, but unless the traffic can be kept off the pavement for at least 10 days it is little superior to a sand filler.

The sand filler is generally used on streets of heavy traffic, the sand being coarse and sharp-grained, and preferably heated before placing. The writer has used with excellent results a bituminous filler between and 1 ft. outside of street-railway tracks and a sand filler for streets. From results obtained he does not consider the extra expense in using bituminous filler justified for such streets unless the traffic be very light. On bridge floors it is better practice to use a bituminous filler with the blocks. After the pavement is rolled, sand to the depth of about $\frac{1}{2}$ in. is spread over the surface and the street is thrown open to traffic.

This method of construction is satisfactory up to a 3 per cent grade, beyond which the blocks are laid in a different manner. The crown should be as light as possible, being just sufficient to shed the water freely, which applies also to the pavements between street-railway tracks.

When the grade of the street exceeds 3 per cent, a creosoted lath is inserted between each cross-row of blocks to leave a space of about $\frac{3}{8}$ in. The lath fills this space practically for two-thirds of the depth of the block and a bituminous filler is used. This method of laying the blocks forms a good foothold for horses, and is satisfactory up to and including a 6 per cent grade.

One of the criticisms made of treated wood-block pavements is that it is slippery, but in the writer's experience he has found that there is very little difference between these blocks and sheet-asphalt pavements. When covered with a light frost or snow, or when the weather is foggy and damp, the pavement may become objectionably slippery.

In traffic observations made at Philadelphia, New York, and other cities, the evidence shown by the engineer at these places indicated that where treated wooden block and granite blocks were on parallel streets, 70 per cent of the teaming went on the wooden blocks.

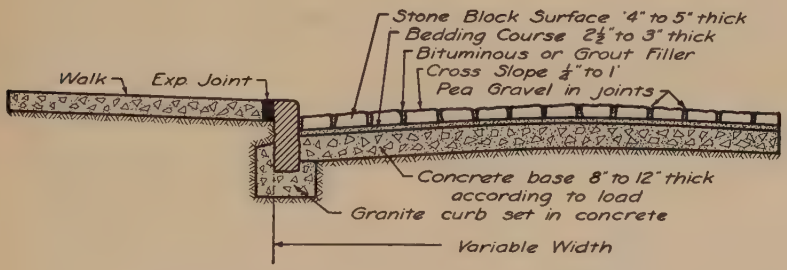
On Stuart Street, in the city of Hamilton the writer laid treated wooden blocks between the street-car rails and granite block between the outside rails and curbs, the pavement being on a 5 per cent grade. Although most of the traffic was of a heavy teaming nature, it was found that fully 80 per cent of the traffic, except on wet days, was on the wooden block.

The first cost of wood-block pavement is undoubtedly higher than that of most of the other paving materials, averaging in the city of Hamilton from $2.85 to $3 per square yard, exclusive of grading. When its cheapness of maintenance, ease of cleaning, low tractive resistance and durability are taken into consideration, this pavement, with its relatively high first cost, will compare favorably and prove ultimately cheaper than one lower in first cost.

CHAPTER XV

STONE-BLOCK PAVEMENTS

The stone-block pavement is one of the oldest types of pavement and one that has been very widely used in Europe and the United States, especially for streets of heavy traffic. For dock and warehouse districts and for streets subjected to very heavy loads, it is the only type of surface having the requisite durability. The earlier pavements of this type often became rough and noisy, but better methods of construction have gradually been developed until those constructed in recent years are high-class surfaces of great durability.


Stone Block Surface 4" to 5" thick
Bedding Course 2½" to 3" thick
Bituminous or Grout Filler
Cross Slope ¼" to 1'
Pea Gravel in joints
Walk
Exp Joint
Concrete base 8" to 12" thick according to load
Granite curb set in concrete
Variable Width

Cross Section for Stone Block Pavement

FIG. 69.

Design of Cross-section.—Since the stone-block pavement is particularly adapted to very severe traffic conditions, it is invariably laid on a foundation of concrete. The foundation is generally of plain concrete, designed on the theory that the block surface adds nothing to the flexural strength of the pavement, but that the block surface bridges the cracks that may develop in the concrete foundation.

The bedding course must be thick enough to compensate for the lack of uniformity in the depth of the blocks.

The thickness of the block surface is generally about 5 in. as it is not practicable to tamp blocks of less depth.

The cross-slope is determined from a diagram like those shown in Chap. IV.

A typical cross-section for a stone-block pavement is shown in Fig. 69.

Kinds of Stone Used for Paving Blocks.—By far the larger proportion of the pavements of this type have been constructed with granite blocks. For this purpose several varieties of granite of varying degrees of hardness are employed. Trap blocks have been employed to some extent, but in recent years the granite block has largely superseded the trap block.

Sandstone blocks have been used to a considerable extent where suitable material is available and where traffic conditions require that the pavement shall be as free from slipperiness as possible and at the same time be one adapted to heavy loads. Quartzite blocks have been used to a limited extent.

Quality of Blocks.—A stone block that is to be used for a pavement will be subjected to impact and abrasion just as any kind of pavement block is, but since stone blocks are laid on streets carrying the heaviest kind of traffic, the abrasion is particularly severe. The stone must be dense and hard and fairly tough. It is also desirable that it wear without polish and therefore with a slightly granular surface so that excessive slipperiness may be avoided. Any stone will likely wear down to a smooth surface, but some kinds of stone are more apt to become slippery than others.

Size of Blocks.—The length of the block cannot be too great or it will not fit closely to the curved section of the pavement, or it will tip under the action of the traffic. The block must not be too short or it will have insufficient bearing to support the loads. Specifications are by no means uniform in the length requirements, but if the blocks are not less than 6 nor greater than 12 in. long they will be well within the usual requirements. Blocks of various lengths are used on the same street, being mixed indiscriminately and laid as they happen to come, so long as joints are broken properly.

If the blocks are too narrow there will be excessive wear on account of the large number of cross-joints and the blocks are likely to be unstable in the pavement if they do not have enough width to give good bearing. Generally speaking, the blocks are seldom made less than 3½ or more than 6 in. wide, but all blocks

used on any job should be of the same width. This is to insure uniformity of the courses and even width of cross-joints.

Thickness and Depth of Block.—Early pavements were laid with blocks 6 or 8 in. deep because it was desired to secure stability to the surface without the necessity of constructing a concrete foundation. Obviously, the blocks could not wear out by grinding down until the pavement was too thin to support traffic. Long before that was possible the pavement would be too uneven for service. More recent practice is to put a good foundation under the blocks and to reduce the thickness of the wearing surface to 5 in., or in exceptional cases, 6 in.

Special Kinds of Blocks.—In addition to the blocks already described, which may be considered the standard type of stone paving block, some special blocks have been tried out in Europe in recent years and may be introduced into the United States.

Grooved Blocks.—For pavements on steep grades, blocks having a groove along the middle are used for the purpose of giving better foothold for horses. The groove is usually ¾ in. wide and ½ in. deep. The blocks are generally 6 in. wide so that there is a transverse groove every 6 in., alternating with the cross-joints which are also 6 in. apart. This type is no longer employed in the United States.

Stone Cubes.—Cubes 4 or 6 in. in size are used to some extent. Commonly they are laid with the edges diagonally across the street, but occasionally they are laid in transverse rows with transverse joints. The cubes used in some German pavements are about 2½ in. in size, and for the Durax pavement, about 3½-in. cubes are used.

Uniformity of Paving Blocks.—Since stone paving blocks are handmade, the degree of uniformity secured depends upon the price that the municipality is willing to pay for them. The stones used have well-defined planes of cleavage so that skilled workmen can produce blocks of any desired degree of uniformity if they are paid sufficiently for it. In specifying the permissible variation, it should be borne in mind that nothing is gained by severe requirements in this direction. For strictly high-class pavements it is desirable to require that the variation from the specified width shall not exceed ¼ in., and in depth not to exceed ¼ or ⅜ in. The faces of the block should be free from bulges or depressions exceeding ¼ in. It is also customary to require that not more than one block per square yard shall show a drill hole

in the side, and that no drill holes shall show at the ends. The sides of the block must be smooth enough to insure room for the filler, and the upper face should be as nearly a plane as practicable to make it. The edges to the upper face should be practically straight lines, and the faces should be perpendicular to each other at the top. It is permissible, however, for the block to be slightly smaller on the bottom than on the top, *i.e.*, a truncated pyramid, but the difference in width at the bottom and top should not be greater than 1 in.

For second-rate paving a greater variation in the various dimensions is permissible, but otherwise the blocks are of the same general shape and size as for first-class pavements.

Requirement for Blocks.—To sum up, the stone block should be made from a fairly tough stone having a crushing strength of at least 16,000 lb. per square inch. If made of granite, the stone should be of fairly uniform composition, the constituent minerals being well distributed and free from an excess of mica. No block that shows signs of disintegration or that is cracked, chipped, or irregular in shape may be used. The dimensions must comply with those specified within ¼ in., and the faces must be substantially plane and free from bunches or depressions. Table XV shows the variations in the several dimensions permitted by American cities:

TABLE XV.—ALLOWABLE VARIATION IN DIMENSIONS OF STONE PAVING BLOCKS

	Length, inches	Width, inches	Depth, inches	Width of joint, inches
Minimum	6	3½	4	¼
Maximum	10	6	8	½
Average specification	..	4	5	⅜

Sand Bedding Course.—Sand has been used quite generally for the bedding course for stone-block pavements. Since there is likely to be a variation of ½ in. or more in the depth of adjacent blocks in a course, the bedding course must be thick enough to permit adjusting the blocks to a uniform surface. Generally, the layer of sand is spread and shaped to a thickness of 2 or 3 in. As in other types of pavement that have been placed on a sand

layer, some dissatisfaction is felt with the use of the sand layer because of its tendency to shift under the blocks. The sand used need be only a fairly clean sand composed of good hard particles and graded from ¼ in. down.

Mortar Bedding Course.—Instead of the layer of sand for bedding the blocks, the lean mortar bed is coming into use and has much to recommend it. The mortar is mixed dry in the proportions of 1 part cement to 3 parts or 4 parts of sand, and spread to the proper thickness. After the blocks have been placed, the surface is sprinkled to give water to hydrate the cement in the mortar bed.

Whether the sand layer or a mortar layer is used, it should be spread, rolled, and struck off to the proper thickness in the manner described for the brick pavement.

Laying the Blocks.—The block layer uses a hammer with a curved metal blade at one end. With the blade he scoops out a depression in the bedding course and places the block so that the top conforms to the finished surface and taps the block gently to place. If the blocks are quite uniform in depth, he may be able to bed them by means of the hammer without scooping out the sand. Special care is taken to have the joints as close and uniform as possible.

The courses are generally laid perpendicular to the curbs, except at street intersections where they are laid parallel to the four diagonals of the intersection. In a few instances, stone-block pavements have been laid with the courses diagonally across the street, but where so laid, they do not wear as well nor furnish as good footing as when laid perpendicular to the curbs, and the method has not been used extensively.

Tamping.—After the blocks have been placed, they are rammed to place with a heavy tamper, a part of the work that must be carefully and thoroughly done. If low places develop under the ramming, the block so affected should be removed, sand added to the bed, the blocks replaced, and again tamped. The blocks are inspected before the ramming begins, and all defective blocks removed and replaced with good ones. After the ramming any blocks that have spalled or split are replaced. The surface when thoroughly tamped is ready for the filler.

Some idea of the importance of proper ramming may be gained from the fact that it requires one man ramming for every three setters, and it would be better if there were one rammer for every

two setters. The object of ramming is not merely to produce a uniform cross-slope, but to bed each block thoroughly so that it will not settle under traffic. If, in bedding the block it is driven below grade, it is raised, the requisite amount added to the bedding course, and the block replaced and again rammed. Some engineers believe it to be desirable to sweep enough gravel of pea size into the joints to fill them about 2 in. before ramming. This serves to hold the blocks more securely in place until the filler has been applied.

Pitch Fillers.—For filling the joints between the blocks, a tar-pitch filler of the grade commonly specified for brick pavements is employed. Sometimes the joint is partly filled with pea gravel before the filler is poured and sometimes no gravel is used. The pitch is applied at a temperature that will insure complete penetration and the joint is filled flush with the surface and then sanded. English practice is to use for a pitch filler a mixture of tar pitch and creosote oil in the proportions of about 1 part of the creosote oil to 10 parts of pitch. In general, English practice is to fill the joints partially with pea gravel before the pitch is poured.

Asphaltic Fillers.—Asphaltic fillers have been used on stone-block pavements to a limited extent only, on account of the difficulty in securing adhesion to the blocks. When adopted, they are applied just as the pitch filler would be.

Cement-grout Filler.—This type of filler is being adopted more and more for the stone-block pavement. As for other types of fillers, the joint is frequently partly filled with pea gravel before the grout is poured. The grout filler is mixed and applied in exactly the same manner as the grout filler for the brick pavement.

Recut Granite Blocks.—Many of the earlier block pavements were laid with blocks 6 to 8 in. deep. These have worn until the pavement is exceedingly rough and uneven. A few cities have tried taking up these blocks and cutting off the rounded part of the head and relaying them, as they are still of sufficient depth to give long service.

Generally the old blocks are taken up and redressed and piled along the sidewalk until the new base course and cushion have been laid, and are then placed exactly as new blocks would be.

Characteristics of the Stone-block Pavement.—The granite-block pavement possesses characteristics adapted to the severest

traffic conditions, and is generally laid only where it is necessary to provide something that will withstand the hardest kind of wear. It will have long life under such conditions if it has been properly laid. It has a tendency to become slippery, especially if the harder granites have been used, and the tops of the individual stones will wear off round unless a good filler is provided. Grout-filled block pavements are more slippery than the pitch filled. In any case, a granite-block pavement is apt to be noisy and somewhat rough. It is not an easy pavement to keep clean or is its appearance as pleasing as that of many types, but as before noted, it is built where a very durable pavement is essential.

The trap-block pavement has all of the characteristics of the granite-block pavement except that it is more slippery after traffic has worn the blocks to a polish.

The sandstone-block pavement is not adapted to such severe traffic conditions as those to which the granite and trap-blocks may be subjected, without undue wear. The sandstone-block pavement is less noisy than the other stone-block pavements, and much less slippery. It has most of the other characteristics of the granite-block pavement.

EXAMPLES OF GOOD PRACTICE

New York City.[1]

The highway officials of New York City consider that for streets with any considerable amount of city traffic, the most satisfactory pavements are granite block, wood block, and sheet asphalt. A considerable part of the latest report of the Bureau of Highways is given to the discussion of stone block, and from this we abstract the following:

Granite block, even under the best conditions, is noisier under steel tires and horse-drawn vehicles than others. It is not so easy to clean. With tar-filled joints a cut can be restored practically as good as the original pavement. Its slightly roughened surface gives a good foothold for horses' hoofs, and its durability is superior to all other types.

The popular idea of granite pavement in this country is based on the old block pavements laid with wide joints, where the head speedily became rounded, producing a cobblestone effect. As laid under the

[1] Gillispie, R. H., "Redressed Granite Blocks," (*Abstract*). *Eng. News-Rec.*, Vol. 69, No. 1, Jan. 3, 1914, p. 24.

present specifications, with flat heads and close joints, it presents a nearly smooth surface and one which cannot wear rounded and uneven. Very hard granite is liable to wear as smooth and slippery as any other type.

It is now universally admitted that granite block for pavement should be accurately cut to standard dimensions and laid with close joints. There are, however, two distinct points of view in regard to the physical composition of the blocks used. That taken by Mayor Gaynor's committee on pavements is to the effect that all deterioration in stone pavement is due to wear consequent on lack of sufficient crushing strength and hardness, and that only the hardest granites can stand the wear of traffic under present conditions.

The other point of view is exemplified in the following statement of Mr. McClure, city engineer of Worcester, Mass., which is of interest, as that city has made extensive use of granite for paving purposes and its streets are admittedly in excellent condition.

"I attribute much of our success in the use of granite blocks to the fact that we have always used the New Hampshire granite, the greater part of the blocks coming from the Marlboro quarries, which is soft enough to wear without polish and hence with a slight degree of slipperiness."

Rounded blocks are not an evidence of lack of hardness, but rather the contrary. Many of the older pavements where the blocks are in the poorest condition, with rounded tops and extremely polished surfaces, are known to have been laid with hard material, the constant friction of horses' hoofs and steel tires on the edges of the blocks, combined with the wide sand joints, producing the above results. Under similar conditions a soft block would wear on the top as well as on the edges, as can be observed in the Medina sandstone pavements of Rochester and Buffalo.

The Fourth Avenue pavement was practically the first laid under the improved specifications. With the exception of certain portions where faulty work was done or where operations of the Department of Water Supply, Gas and Electricity and the gas company have injured it, and excepting, also, the railroad area including between limits 2 ft. outside of the tracks where the pavement has not yet been relaid, and where, due to the poor condition of the rails it has settled in many places, the surface is good, and the blocks show little evidence of wearing round after two seasons of service. Work is shortly to be started in the railroad area, which is to be entirely repaved with new blocks after the rails have been changed.

CHAPTER XVI

BITUMINOUS ROAD AND PAVEMENT MATERIALS

Bituminous materials, particularly the native asphalts, have been used for various purposes almost since the beginning of history, and the earlier uses were for purposes where the binding or waterproofing properties of the material could be utilized but they were not widely used for road construction. The materials were obtained from the deposits of natural asphalt that are found in so many places all over the world. These materials were called asphalt or pitch.

Asphalt.—The term *asphalt* was therefore first applied to the materials that had exuded from the earth in the form of a viscous liquid and may or may not have hardened from exposure and which might be fairly free from inorganic matter or might have impregnated porous rocks or sands.

As the use of this material became more general the term asphalt was applied to a wide variety of substances that were somewhat alike in physical characteristics. Some of these were obtained from natural deposits and some were produced by commercial processes.

The asphalts employed for highway purposes are sufficiently sticky to serve as binders for mineral matter and are soluble in varying degrees in carbon disulphide, benzol, chloroform and similar solvents. The portion of the asphalt that is soluble in carbon disulphide is called bitumen and is the binding material. The insoluble portion consists of sand, earthy material, and partially or wholly decomposed animal or vegetable matter. The native asphalts differ widely in solubility, while the asphalts produced by refining petroleum are completely soluble in carbon disulphide, or nearly so.

Origin of Asphalt.—It is generally accepted that asphalts have their origin in petroleum and that the native asphalts are in reality formed by the weathering of petroleum that has reached the surface of the earth, or cavities exposed to the air, from underground pools of petroleum.

The petroleums vary in composition from those that consist largely of paraffinaceous compounds to those that are almost wholly devoid of such substances. It has become the practice to refer to those first mentioned as paraffine-base petroleums and to those wholly devoid of hydrocarbons of the paraffine series as asphalt-base petroleums. Petroleums that contain some hydrocarbons of the paraffine series are known as mixed-base petroleums.

The exudations of the various types of petroleum naturally partake of the characteristics of the petroleum from which they come. Those that are the result of the weathering of asphalt-base petroleum are known as natural or native asphalts. Many kinds of waxes and pitches are found in exudations from the mixed base and paraffine base petroleums and these are widely used in the arts but are not of interest to the highway engineer.

The natural asphalts therefore have their source in underground pools of petroleum from which the materials reach the earth's surface in a manner analogous to a spring of water. In flowing through the crevices and porous layers of the earth's crust the petroleum gathers up variable quantites of earthy material and fine sand. Natural asphalts therefore usually contain inorganic material insoluble in carbon disulphide. Upon reaching the surface of the ground the material spreads out in a layer over the surface or forms a small lake in some depression in the earth's surface. In this exposed state the lighter oils gradually evaporate until the deposit reaches a solid or semi-solid state. However, some of the deposits are quite soft.

As time passes, vegetable matter from vegetation in the vicinity of the deposit becomes mixed with the asphalt and hence natural asphalts usually contain some organic matter not soluble in carbon-disulphide.

Oil Asphalts.—Oil asphalt is the residue from the fractional distillation of petroleum and is therefore somewhat analogous to the residue that remains after exudations of petroleum have weathered from exposure to the elements. In either instance the character of the residue will be determined largely by the nature of the petroleum from which it came. Oil asphalts are classed as asphalt-base, mixed-base or paraffine-base residue but only the two first named have a general usefulness in highway construction. These residues are produced in a variety of consistencies and are of varying degrees of suitability, depending

upon the physical characteristics of the particular material.

The asphalt-base residues and those mixed base residues that contain but little paraffinaceous material are most widely used for pavement surfaces. In North America they are obtained principally from the petroleums of California and especially from those of Mexico. Various petroleums obtained in the mid-continent fields of the United States yield residues that can be used for some kinds of highway construction other than for the sheet types of pavements and bituminous road surfaces.

Definition of Asphalt.—Asphalt is defined by the American Society for Testing Materials as follows: "Asphalts are solid or semi-solid native bitumens, solid or semi-solid bitumens obtained by refining petroleum, or solid or semi-solid bitumens which are combinations of the bitumens mentioned, with petroleums or derivatives thereof, which melt upon the application of heat and which consist of a complex mixture of hydrocarbons and their derivatives, of complex structure, large cyclic and bridge compounds."

It will be noted from this definition that the term asphalt should be applied only to the solid and semi-solid materials. Asphalts are black or brownish black in color, are more or less sticky when softened by heat and may or may not have distinctive odors. The odor is not pronounced in any case except when the material is hot. With a little practice it is possible to note some difference in the feel of asphalts, those containing paraffine having a slightly greasy or unctuous feel. Those that contain considerable amounts of mineral matter have a slightly gritty feel.

Bitumen.—Attention has already been directed to the fact that oil asphalts are almost completely soluble in carbon-disulphide, while natural asphalts contain varying percentages of matter insoluble in carbon-disulphide. The soluble material is called bitumen and is the portion of an asphalt that is useful as a binding agent, therefore the characteristics of the bitumen in an asphalt determine the usefulness of the asphalt.

Bitumen Defined.—Bitumen is defined by the American Society for Testing Materials as follows: "Bitumen is a mixture of native or pyrogenous hydrocarbons and their non-metallic derivatives which may be gases, liquids, viscous liquids or solids, and which are soluble in carbon disulphide."

Native hydrocarbons are those found in the natural asphalts; pyrogenous hydrocarbons are those found in products produced by fractional or destructive distillation such as the petroleum residues and the tars.

Value of Bitumens.—Since bitumen, like many organic compounds, is a substance of very complex chemical composition its physical characteristics are also exceedingly diverse. The chemical characteristics of a particular asphalt can in general be changed but little by the process to which the materials are subjected in their preparation for highway work. The highway engineer must select from the numerous supplies available the one that affords a material suitable for his purposes or by combining commercial materials secure a product with the desired characteristics.

Certain physical characteristics can be modified within limits by established methods. Of these the most important is consistency and that characteristic is the primary consideration in determining the use for which a material is suitable. Conversely the first consideration in specifying a material for a particular purpose is to secure one that is of the right consistency. Since asphalts soften when heated, consistency is a relative property and to afford a suitable basis for comparison, it is desirable to consider the relative consistency at a standard arbitrary temperature and 77°F. has been chosen as the standard temperature for comparison.

The specific gravity of an asphalt is to a considerable extent inherent but for any type of material the softer it is the lower the specific gravity. Ductility is also inherent in the material but will vary somewhat with consistency. The softening point varies with consistency, being higher for hard materials than for soft. In fact the real reason for varying the consistency is in most cases to secure a proper softening point. Asphalts of different types but of the same consistency will not necessarily have the same softening point.

Other properties, such as fixed carbon content and the degree of solubility in various solvents used in asphalt testing, are inherent in the various materials and are of significance principally as means of identifying the materials.

In preparing specifications for asphalts it is necessary to recognize that certain characteristics are inherent in the materials, certain are susceptible to small variations during the preparation

of the materials and that still others may be varied at will through a wide range of values. Aside from consistency, melting point, flash point, and perhaps ductility, the properties of asphalts have little relation to their usefulness for highway purposes and when limits are prescribed for other properties it is generally done to insure the use of materials from certain acceptable sources. Experience is the only really dependable guide to follow in interpreting the significance of the results of tests of these materials.

NATURAL ASPHALTS

Natural asphalt is a bituminous material that is obtained from deposits existing in nature in which the material is of such character that it needs only to be freed of foreign matter to be suitable for use. This is the class of material originally known exclusively as asphalt.

Trinidad Asphalt.—The largest and best known of the natural deposits is that on the Island of Trinidad in the British West Indies, which is known as the Pitch Lake. This deposit is in the nature of a lake of about 125 acres extent and having a depth of more than 135 ft. in places. The material obtained from this deposit contains pieces of wood, gas, water, and a considerable quantity of fine sand and clay. The refined material is of uniform quality and contains 56.5 per cent of pure bitumen, the remainder being sand, clay, and organic matter insoluble in carbon disulphide. Other deposits of similar material are scattered over the islands, but they are of much less importance commercially. Trinidad asphalt has been long and widely used as a binder for sheet asphalt and asphaltic concrete pavements. It is unlike any other asphalt known.

Trinidad Petroleum.—A heavy asphaltic petroleum oil is obtained from wells on Trinidad Island, and this oil field has been extensively developed. This material contains a relatively small amount of the lighter oily constituents common to petroleum, and the body of the oil is of a truly asphaltic nature and exceedingly sticky and stable. This material is soluble in carbon disulphide to the extent of 99.9 per cent. It is refined and marketed as a dust layer and as a binder for the construction of bituminous carpets.

Bermudez Asphalt.—Another well-known deposit of natural asphalt is on the north coast of Venezuela and is known as the

Bermudez deposit. It is a comparatively shallow deposit, being in most places about 7 ft. thick but has an area of about 900 acres. The material has exuded from the earth and spread over a swampy area which is often covered with water. It contains decayed vegetable matter, sticks and a little clay and water. The water-free material is somewhat variable in composition and contains from 93 to 97 per cent pure bitumen with an average of 95 per cent. The remainder is clay and organic matter insoluble in carbon disulphide. Bermudez asphalt is widely used as a binder for sheet asphalt, asphaltic concrete and macadam surfaces.

Cuban Asphalt.—Several deposits of natural asphalt exist in Cuba, most of which are of rather recent development. In general, the Cuban asphalt that has been utilized for paving purposes resembles slightly the Trinidad Lake asphalt, but is more variable in its characteristics. It contains from 65 to 75 per cent of bitumen, the remainder being sand and clay and organic matter insoluble in carbon disulphide. Cuban asphalt is used to some extent for sheet and asphaltic concrete pavements, and for macadam surfaces.

Mexican Asphalt.—Deposits of natural asphalt also exist along the Gulf Coast of Mexico, and for a short distance inland in the Tuxpam district. These deposits are variable in composition, but are being developed rapidly and will likely be used extensively in the future. The various deposits contain from 60 to 99 per cent pure bitumen. The Mexican asphalts have been used principally for sheet and asphaltic concrete surfaces.

Miscellaneous other deposits of natural asphalt are found throughout the world, and the material has been an article of commerce from the earliest times. Asphalt is found in the vicinity of the Dead Sea, and its properties and value have been known locally from the earliest Bible times. The Dead Sea deposits have not been developed on a large scale. Other deposits in Asia and Europe have been known and utilized for centuries, and many European cities have been paved with asphalt obtained from these sources.

Deposits of minor importance are known in South America, and in Texas and California.

Gilsonite.—Deposits of a bitumen known as gilsonite, which is not an asphalt, are found in parts of Colorado and Utah. It is of importance because it is practically pure bitumen, and has been extensively used in the paving industry, being fluxed with

an asphaltic residue and forming an exceedingly tough and rubbery cement.

Natural Rock Asphalt.—In many parts of the world there are extensive deposits of limestone or sandstone rock which by some process of nature have become impregnated with asphalt, usually in the form of a soft maltha. The best known deposits in the United States are in Kentucky, Oklahoma, Texas, and Southern California, while those in Germany, France, Sicily, and Russia are best known abroad. This class of material has had a limited use for sheet-asphalt surfaces in the United States, but has been extensively used in Europe. As might be expected, the rock asphalts vary greatly in character and few of them can be used for paving purposes without the addition of either sand or bitumen or both. The rock asphalts are also extensively used for mastic floors in factories and laboratories.

Refining Natural Asphalts.—It is doubtless apparent from the foregoing that the various materials discussed differ greatly in consistency and other physical characteristics, and that all must be prepared in some manner to render them suitable for paving purposes. In some of the deposits the materials vary from hard pitches to soft asphalts or malthas that flow slowly at ordinary temperature; in other deposits the consistency is fairly uniform.

A brief description of the method of refining the Trinidad Lake asphalt will indicate in a general way the usual preparation necessary before natural asphalts can be used for paving purposes.

The Trinidad Pitch Lake is some miles inland and about 140 ft. above sea level. The asphalt is broken out of the surface in irregular pieces by means of picks, and is loaded onto small cars. These are hauled out from the region of the lake and the removable bodies of the cars attached to a cableway and transported to the dock where the material is loaded into vessels. When the cargo reaches the refinery (Maurer, N. J.) the asphalt is picked loose in the hold of the vessel and removed to the melting tanks. It is then heated by means of steam coils to a temperature exceeding 212°F., after which it is agitated by means of jets of steam from pipes in the bottom of the tank. As the heating progresses the entrained water and gas are given off and the sticks and other vegetable matter are removed. The material is then drawn off into barrels to be shipped to the place of use. There it is fluxed with a suitable petroleum oil to reduce its consistency to that desired for the paving cement.

PETROLEUM ASPHALTS

Petroleum, as is well known, is composed of complex and variable mixtures of hydrocarbon compounds, and, in the process of refining, the various burning and lubricating oils are distilled off, leaving a residue which is a black, viscous substance. The residue may consist of hydrocarbons of the paraffine series or may contain none of them, in which case it is called asphaltic, or it may be composed of both classes of material. Hence petroleums are referred to as asphaltic, semi-asphaltic or paraffine, depending upon the character of the basic compounds. The residue from the asphaltic and semi-asphaltic petroleums are converted into paving materials by various processes which will now be described briefly.

Residual Asphalts.—The residue from refining some kinds of petroleum is suitable for road construction without further treatment, and is marketed substantially as obtained in the process of refining the petroleum. This is particularly true of California and Mexican oils. In other instances the residues are either too hard or too soft and must be brought to a suitable consistency by variation in the refining process or by the addition of asphalts or fluxes from other sources. When an asphaltic material left from the refining process is suitable for use without further treatment, it is known as a residual asphalt. Residual asphalts are employed for dust laying, for carpeting, and for macadam construction, and when properly fluxed, for sheet pavements.

Gilsonite Products.—Some petroleum residues are unsuitable for paving purposes because of the poor quality of the bitumen they contain, or because of their being of improper consistency. Gilsonite can be mixed with such of these residues as are of an asphaltic nature and thus produce a paving material of suitable character. The mixture may or may not be "blown" as described below. It is used for all classes of road construction where the mixing processes are employed, and for penetration macadam.

Blown Oils.—Petroleum residues are sometimes subjected to the process known as blowing, which improves them for use in paving work. The process consists in first heating the residue to a temperature of about 200°F. Air is then blown into the material from perforated pipes in the bottom of the tank, the heating being meanwhile continued. Under this treatment the temperature gradually rises to about 400°F. at which it is held

until the material is brought to the desired consistency and quality. The process is usually continued for from 5 to 20 hr. With some grades of residue it is also necessary to add gilsonite or some other material rich in bitumen to produce a paving material of good quality. Products manufactured in this way are known as *blown oils*. The blowing has the effect of producing a waxy asphalt of low ductility but of reasonable stability. The blown oils are used for sheet asphalt and asphaltic concrete, and for mixed and penetration macadam construction.

TARS

Tar is classified commercially as a bituminous material, although the bitumen it contains is entirely unlike that contained in asphaltic materials.

Coal tar is a byproduct of the *destructive distillation* of coal. If the tar is produced during the manufacture of illuminating gas from coal, it is commonly called *gas-house tar*. If it is produced as a byproduct in the manufacture of coke, it is known as *coke-oven tar*. The gas-house tar is produced at a higher temperature than the coke-oven tar, and usually contains more free carbon (soot) than the coke-oven tar, due to the differences in processes of which the tars are a byproduct. Tars are almost pure bitumen, aside from the free carbon. They have the same general appearance as asphalts but have the characteristic and familiar tar odor which differs from the odor of any of the asphaltic materials. Tars are refined to prepare them for paving purposes, the process consisting in distilling off the water and lighter or more volatile oils, leaving a residue of the desired consistency. Coal tar is used for penetration and mixed macadam, and for carpeting.

Cut-back Pitches.—Tars are used widely in the arts in obtaining the basic materials for dyes, medicines, etc., and incident to manufacturing these products, residues are often obtained that are too hard for paving purposes. These are softened or "fluxed" by means of lighter distillates obtained as a byproduct from other manufacturing processes and the resulting mixture is known as a *cut-back pitch* or simply as a "cut back." These tars are manufactured with various consistencies suitable for the different classes of macadam road work.

Water-gas Tar.—Water-gas tar is produced as a byproduct of the manufacture of illuminating gas from oil and water. It is

the result of *destructive distillation* or "cracking" of a petroleum oil. It has the same general appearance as coal tar and has much the same odor, but is generally thought to be less useful for road purposes. It also differs in that it carries a much lower amount of free carbon than do the other classes of tars. It is refined and marketed for all classes of macadam construction.

Mixtures.—Many road binders and paving cements are mixtures of two or more of the classes or types of bituminous materials that have been mentioned. As an illustration, the practice of mixing California residues with Texas residues might be mentioned. Water-gas tars and asphaltic materials are also mixed in manufacturing some brands of road materials. These products often appear to have desirable physical properties, but their behavior under traffic has not yet been fully established.

Fluxes.—A flux is a soft bitumen or bituminous oil that is mixed with a harder bitumen to soften it. The ordinary asphalt cement is usually a mixture of a hard bitumen and a flux. The practice of softening a hard pitch with tar distillates has already been mentioned as a fluxing process and the distillate thus used is a flux.

Fluxes for asphaltic materials are obtained from petroleum and are of two classes, semi-asphaltic and asphaltic, the classification depending upon the predominating basic compounds of which the flux is composed as has been mentioned in connection with petroleum asphalts. Paraffine fluxes were at one time quite widely used but are now off the market.

Semi-asphaltic flux is obtained principally from the mid-continent oil fields. As the name indicates, the basic compounds are partly asphaltic and partly paraffine. This is one of the best grades of flux obtainable.

Asphaltic flux is obtained principally from the California petroleums. It is a dense, heavy flux and a larger proportion of it must be used with a hard bitumen than of other types. When carefully prepared so that it will remain soft in the pavement, it can be used successfully.

The properties of fluxes obtained from the various sources will vary greatly but certain characteristics are essential to all of them.

1. The flux should be prepared at high temperature, yet without injury to the material from overheating. It is essential that the paving cement in which the flux is used remain unchanged for years, and, unless the flux has been prepared at a temperature

near 450°F., it is likely to volatilize in service and leave a brittle pavement surface.

Since the sheet asphalt and asphaltic concrete pavement surfaces are usually mixed at temperatures ranging from 250 to 350°F., it is necessary to use a flux that will not catch fire, *i.e.*, "flash" at these temperatures, which is an additional reason why the flux should be manufactured at high temperature.

2. The flux should be fluid enough to have the property of mixing with hard bitumens in such a manner that it will reduce the harder materials to a proper consistency without the necessity of using an excess of about 30 lb. of flux to 100 lb. of the harder bitumen. This characteristic is only partly dependent upon the fluidity of the flux, being influenced also by the character of the hydrocarbons of which it is composed.

3. The flux should consist of stable compounds so that it will not change after it has been incorporated in the pavement. This property should not be confused with volatility. A volatile flux will evaporate and cause the pavement to become brittle. Other fluxes are composed of unstable compounds that change in the pavement with the passage of time. The result may be a bituminous cement that is of good binding properties when the pavement is laid, but which loses its binding properties with time, and the pavement may fail as a result.

Asphalt Cement.—Asphalt cement is defined as a fluxed or unfluxed asphaltic material, especially prepared as to quality and consistency so as to be suitable for direct use in the manufacture of asphaltic pavements, and having a penetration between 5 and 250. Generally it has a penetration between 40 and 70.

The asphaltic cement, as its name indicates, is an asphaltic material that is used to bind together the particles of sand or other mineral matter of which the pavement is composed. It is analogous in purpose to the portland cement used in concrete.

The unfluxed asphalt cements are usually petroleum products, manufactured to the proper consistency for use without further treatment. They are received at the paving plant ready for use.

A fluxed asphalt cement is usually made at the paving plant. The hard asphalt and the flux are received separately and combined at the plant prior to mixing with the mineral aggregate.

CLASSES OF COMMERCIAL BITUMINOUS MATERIALS

Commercial bituminous materials are most conveniently classified according to the purpose for which they are manu-

factured. For most kinds of bituminous construction there are a large number of brands of material available, representing many varieties and types of bituminous products.

The first consideration in selecting a material for a specific piece of construction is to secure a type of material that is known to be satisfactory for that particular purpose. Consider the case of materials for sheet asphalt and for macadam construction as concrete examples. Tars are not used for sheet asphalt but asphalt base (Mexican and California petroleum products) and natural asphalts are used. For penetration or mixed macadam, tars, blown petroleum asphalts, Mexican asphalts, and natural asphalts are used.

The second consideration is to secure a material of the proper consistency for the work. Nearly any variety of bituminous material can be furnished in any desired consistency from liquid to solid.

The following outline indicates in a general way the relative consistencies desired for the various purposes:

Purpose	Consistency at ordinary room temperature (77°F.)
Dust layers for earth, gravel and macadam roads.	Liquid—flow freely.
Carpeting mediums.	Viscous liquids—flow slowly.
Penetration and mixed macadam.	Semi-solid—will scarcely flow.
Asphalt cements for sheet asphalt and asphaltic concrete.	Solid—will not flow but a lump will flatten down after several hours.
Fillers for block pavements and for maintenance of cracks.	Solid—usually but little harder than asphalt cements.
Fillers for expansion joints (except pre-molded type).	Solid—usually somewhat harder than asphalt cement.

The following are the United States Commercial Standard Consistencies for asphalt, and specifications should always conform to one of these standard asphalts:

(1) For construction of sheet asphalt, asphaltic concrete, and asphalt macadam pavements, and also for surface treatment:

STANDARD PENETRATION LIMITS AT 77°F.

25 to 30	50 to 60	100 to 120
30 to 40	60 to 70	120 to 150
40 to 50	85 to 100	150 to 200

(2) For joint filler for various types of construction:

Standard Penetration Limits at 77°F.	
30 to 50	60 to 70
50 to 60	85 to 100

The first is used primarily for brick pavements, and does not require the admixture of sand, whereas the three last named, which are identical with three of the grades adopted for asphalt pavement construction, are those which would ordinarily be used in admixture with sand to produce an asphalt grout.

The following analyses indicate the general character of some of the commercial bituminous materials now being used:

Dust Layers for Earth Roads

	No. 1	No. 2
Specific gravity at 25°C	0.94	0.93
Specific viscosity (Engler) 50 cc. at 50°C	12	14
Total bitumen	99.86 per cent	99.9 per cent
Fixed carbon	2.16 per cent	6.8 per cent
Volatilization loss on 50 g., 5 hr. 163°C	0.92 per cent	11 per cent

Dust Layers for Gravel and Macadam Roads

A. Tar:

	No. 1	No. 2
Specific gravity at 25°C	1.13	
Specific viscosity on 100 cc. at 40°C	24.6	
Free carbon (insoluble in benzol)	5.2 per cent	
Distillation fractions by weight:		
Total distillate up to 170°C	1.4 per cent	
Total distillate up to 270°C	28.0 per cent	
Total distillate up to 300°C	31.0 per cent	

B. Petroleum Oil:

Specific gravity at 25°C	1.01	1.04
Consistency by float test at 50°C	88 sec.	18 sec.
Total bitumen	99.7 per cent	99.9 per cent
Asphaltenes	19 per cent	
Fixed carbon	11.2 per cent	8.58 per cent
Volatilization loss 50 g., 5 hr., 163°C	2.01 per cent	7.4 per cent

C. Tar for Gravel-road Maintenance:

Specific viscosity, 50 cc. at 40°C	9.9
Free carbon	4.04 per cent

Distillation fractions by weight:

0 to 170°C.,	1.0 per cent
0 to 270°C.,	23.3 per cent
0 to 300°C.,	31.8 per cent

Softening point of residue for distillation, 49.6°C.

Carpeting Mediums and Binders for Mastic

A. Tar:

Specific gravity at 25°C	1.22
Specific viscosity (Engler) 100 cc. at 100°C	14
Free carbon (insuluble in benzole)	13.6 per cent
Distillation fractions by weight:	
Total distillate up to 170°C	0.0 per cent
Total distillate up to 270°C	15.0 per cent
Total distillate up to 300°C	20.6 per cent

B. Asphalt:

Specific gravity at 25°C	0.985
Float test at 50°C	120 sec.
Penetration at 25°C., 50 g., 5 sec. at least	350
Loss at 163°C., 5 hr	7 per cent
Total bitumen	99.5 per cent
Fixed carbon	6 per cent
Percentage bitumen insoluble in 86° naphtha	15 per cent

Binders for Penetration and Mixed Macadam

A. Tar:

Specific gravity at 25°C	1.24
Melting point, cube-in-water method	50°C.
Free carbon (insoluble in benzole)	17 per cent
Distillation fractions by weight:	
Total distillate up to 170°C	0.0 per cent
Total distillate up to 270°C	8.0 per cent
Total distillate up to 300°C	12.0 per cent

B. Fluxed Native Bitumen:

Specific gravity at 25°C	1.054
Consistency by penetration method at 25°C., 100 g., 5 sec	95.6 per cent
Asphaltenes	26.6 per cent
Fixed carbon	11.1 per cent
Volatilization loss, 50 g. at 163°C	4.26 per cent
Ductility	48 cm.

C. Petroleum Product:

Specific gravity at 25° C	1.03
Consistency—penetration at 25°C., 100 g., 5 sec	100
Total bitumen	99.9 per cent
Asphaltenes	21 per cent
Fixed carbon	16 per cent
Volatilization loss 50 g., 5 hr., 163°C.	0.12 per cent

Asphalt Cements for Sheet Asphalt and Asphaltic Concrete.—Native asphalts fluxed to the correct consistency by the admixture of soft petroleum asphalt and asphalts prepared from Mexican or California petroleum are the principal types of asphalt cement now in use. Of the native asphalts, Trinidad and Bermudez are the only ones having extensive used in the United States. In recent years the Mexican oil asphalts have come into favor and their production has increased at an enormous rate. Aside from the specification requirements intended to secure the desired type of material, the most important consideration for an asphalt cement is to secure the proper consistency. This is determined on a basis of climatic conditions and traffic, but there is nothing that approaches standardization of consistency. The manufacturers of oil asphalt cements prepare asphalts of many consistencies and since the native asphalts are fluxed at the mixing plant it is an easy matter to secure any desired consistency and that discourages standardization. The following table was prepared by Prevost Hubbard[1] to serve as a guide in determining the consistency to adopt for any specific piece of work.

Recommended Consistency in Standard Penetration

Traffic	Temperature		
	Low	Moderate	High
Light	50–60	50–60	40–50
Moderate	50–60	50–60	40–50
Heavy	40–50	40–50	30–40

Analyses of Asphalt Cements

A. Petroleum Products:

	"Texaco"	"Stanicolo"
Specific gravity at 25°C	1.03	1.042
Consistency by penetration at 25°C., 100 g., 5 sec	54	56
Total bitumen	99.9 per cent	99.9 per cent
Asphaltenes, insoluble in 86°B. naphtha	25 per cent	23 per cent
Fixed carbon	11.6 per cent	16.7 per cent
Melting point R & B	140°C.	132°C.
Ductility	75 cm.	100 cm.
Flash point	250°C.	270°C.
Volatilization loss on 50 g., 5 hr., 163°C	0.06	0.055 per cent

[1] Chemist for the Asphalt Association, New York City.

B. Fluxed Native Bitumens:

	"Bermudez"	"Trinidad"
Specific gravity at 25°C	1.045	1.24
Consistency by penetration at 25°C.	55	58
Total bitumen	96.2 per cent	74 per cent
Asphaltenes, insoluble in 86°B. naphtha:		
Ductility	32 cm.	28 cm.
Fixed carbon	12.6 per cent	16.9 per cent
Volatilization loss 50 g. at 163°C.	0.5 per cent	0.7 per cent

FLUXES

A flux is a soft petroleum asphalt, usually either a viscous liquid or semi-solid, employed to soften the natural asphalts. Often the flux is a material that might be used for a binder for penetration or mixed macadam. Fluxes are obtained principally from the mixed base or the asphalt base petroleums.

Petroleum Flux

Specific gravity at 25°C	1.008
Consistency by float test at 50°C	185 sec.
Total bitumen	99.8 per cent
Volatilization loss, 50 g. at 163°C	0.4 per cent
Flash point (open cup)	190°C.

Fillers for Block Pavements

A. Petroleum Asphalt:

	No. 1	No. 2
Specific gravity	1.015	1.044
Melting point R & B	69°C.	57°C.
Penetration at 25°C	32	41
Volatilization loss 50 g., 163°C	0.7 per cent	0.02 per cent

B. Tar:

	No. 1	No. 2
Specific gravity at 25°C	1.22	
Free carbon	24 per cent	
Melting point, cube-in-water method	135°F.	
Distillation fractions by weight:		
Total distillate up to 170°C	0	
Total distillate up to 270°C	2 per cent	
Total distillate up to 300°C	5 per cent	

CREOSOTE FOR WOOD PRESERVATION

Creosotes are tar products that are often classed as bituminous materials, and they are discussed in the chapter on wood-block pavements.

Problems

1. Write a specification for a blown petroleum asphalt filler to be used for a block pavement. Word the specification and limit the properties of the material in such a way that no other type of material will comply with the specification.
2. Write a specification for an asphalt cement to be used in a city in the northern part of the United States for a street in a high class retail district. Assume it is desired to close the specification to all materials except a fluxed native bitumen.
3. Write a specification for an asphalt cement to be used in a sheet asphalt pavement for a strictly residential street in a small city in one of the southern states of the United States. Assume that the specification is intended to admit any suitable type of asphalt.
4. Identify each of the following materials from the analyses, which are assumed to have been made by a reputable laboratory, and state the purpose for which material was probably intended.

Analysis No. 1:

Specific gravity at 25°C	1.18
Melting point, R & B method	50°C.
Free carbon	15 per cent
Distillation fractions by weight:	
Total distillate up to 170°C.	0.5 per cent
Total distillate up to 270°C.	10 per cent
Total distillate up to 300°C.	11 per cent

Analysis No. 2:

Specific gravity at 25°C	1.41
Total bitumen	56.4 per cent
Fixed carbon	15 per cent
Asphaltenes	24 per cent

Analysis No. 3:

Specific gravity at 25°C	1.032
Penetration at 25°C	60
Total bitumen	99.8 per cent
Asphaltenes	23.6 per cent
Ductility at 25°C	100 cm.
Fixed carbon	15.8 per cent
Flash point	290°C.

CHAPTER XVII

DUST LAYERS AND BITUMINOUS CARPETS

I. DUST SUPPRESSION ON EARTH ROADS AND STREETS

The earliest attempts to use asphaltic oils and petroleum residues for laying the dust and preserving the surface of earth roads and streets were made in California. On account of the nature of the soil and the excellent quality of the oils available, the California experiments gave promising results and attracted wide attention. Similar attempts in other portions of the United States and with oils of a different kind and under other soil and climatic conditions have not been so successful. This is particularly true of those attempts that have been made to secure permanent results with mixtures of heavy asphaltic oils and earth. In most cases the results have been of little value and have almost universally failed if the roads carried heavy traffic.

Where oils of a more fluid nature have been used to suppress the dust on earth roads the results have been more satisfactory and there has been a gradual increase in the use of such oils for dust prevention.

Preparation.—If a road or street is to be oiled for the first time, preparations should be started some weeks before the oil is actually applied.

The effect of the oiling is to render the earth partially impervious to moisture and if the surface of the road be uneven when oiled or becomes uneven afterward, the depressions will become basins for holding water. Traffic will gradually work the soil and the water thus retained into mud, deepening the depressions to the serious detriment of the street. If the street be smooth and well crowned the water will run to the gutters so quickly that only in long-continued wet weather will the street be softened to any great extent and therefore traffic will not make any considerable amount of mud on the surface.

The principal object in oiling a street is to prevent dust; therefore, there should be no dust on the street when the oil is applied.

If dust has formed, it had better be removed, which costs something. It is therefore cheaper to treat the surface before the dust has formed, if possible.

For the best results the street oiling should be planned ahead and the preparation of the street be carried out in the early summer so that the oiling can be done before a layer of dust forms on the street.

Grading.—Good results with oil cannot be expected on a flat and poorly drained street. Early in the summer the street should

FIG. 70.—An oiled earth road.

be carefully rounded with an even slope from the middle to the gutter. The gutter or ditch should be deep enough to carry the water readily and to permit a slope of about 1 in. to the foot from the middle of the street to the gutter. Generally, the bottom of the gutter should be about 18 in. below the middle of the street where the width of the street is not over 35 ft. between gutters. This is about right on a residence street. On a business street having a width of 50 ft., the bottom of the gutter should be at least 2 ft. below the middle of the street.

After the street has been shaped with a grader, it will undergo a period of settling during which some depressions and uneven places will appear. These should be filled with earth and the entire roadway be kept dragged until it finally becomes hard and smooth and free from depressions.

It is very important to secure a firm, smooth surface for the oil, and the small expense incurred will be more than made up by the increased effectiveness of the oil treatment.

When the street has been brought to this stage it is ready for oiling. If the oiling is delayed until a layer of dust has formed on the street it is best to scrape off most of it before oiling.

The decision to oil a street may sometimes be reached after the summer is well along and the streets have become hard and dry. In that event, it is not advisable to do any extensive earthwork because in continued dry weather newly placed earth will not compact readily and if oiled before being well packed the results are unsatisfactory. Such a condition is not ideal and only mediocre results can be expected.

Kinds of Oils to Use.—The various kinds of oils employed for this purpose have already been discussed at length in Chap. XVI.

Applying Oil.—After the street has been prepared as described, the oil is applied at the rate of not less than ⅓ gal. nor more than ½ gal. per square yard of surface. If the street has never been oiled before, or if more than a season has elapsed since a previous oiling, it will be necessary to use about ½ gal. per square yard, but if the street has been oiled regularly each season, about ⅓ gal. per square yard is sufficient after the first year. For a street in a small-town business district, it is necessary to oil every year, using about ½ gal. per square yard of surface for each oiling. In many towns it is desirable to oil the business streets twice a year.

After the oil has been spread it is allowed to stand for about a day without being covered, to permit it to soak into the surface. It is then covered with just enough sand to keep the oil from picking up. Emphasis is placed on the importance of employing sand for this purpose rather than dust from the old road surface. The amount of sand needed is small and at any reasonable price the benefits derived from the sand justify its use wherever it can be secured.

After the road has been put into service it may be apparent that more sand is needed in spots to prevent vehicles from picking up the oil, and such places should be covered lightly, the operation being repeated two or three times if necessary.

When a street is oiled the second time, the method to be followed is exactly the same as is followed the first time, except

that the quantity of oil may be reduced to about ⅓ gal. per square yard of surface. It is advisable to repeat the oiling the second year in any case, and it may be then omitted the third year and resumed the fourth year. Better results would be obtained if the treatment were repeated every year.

Results to be Expected.—Surface oiling forms a surface covered with a layer of granular or finely powdered soil which is oil-saturated and consequently does not blow about readily. The suppression of dust is the principal benefit to be expected. Beneath the thin layer of loose, oil-soaked soil the firmer portion of the street is saturated with oil for a depth that varies from 1 in. to perhaps 6 in.

Water penetrates this layer rather slowly. If the street has plenty of cross-slope so that water does not stand on the surface, only a small amount of mud will form under light or moderate traffic. A street that is oiled systematically for a series of years gradually acquires an oil-soaked crust which becomes more and more impervious as the oiling is repeated. An oiled street never gets to the place where it will not be muddy in those seasons of heavy rainfall nor will the surface be stable in ordinary wet weather if the road carries a heavy traffic.

Unloading the Oil from Tank Cars.—The oils used for dust suppression can be purchased so much more cheaply in tank-car lots than in barrels that it is always advisable to purchase in such lots. If a siding on an embankment 8 or 10 ft. high is available, the car can be placed thereon and the oil allowed to run into the sprinkler wagon through a pipe connected to the tap in the bottom of the tank car.

When such a siding is not available the oil must be pumped from car to wagon. For this purpose the ordinary tank pump used with traction engine tanks is as good as anything. It should be placed on top of the tank car with all connections made of pipe, as hose does not last long in oil. If a small steam- or gas-engine-driven pump be available, it will, of course, be faster than a hand pump.

Cost of Surface Oiling.—The total cost of oiling earth roads or streets will vary between the following limits, assuming a treatment of ½ gal. per square yard of surface, and the cost of oil to be 4 cts. per gallon.

TABLE XVI.—COST PER SQUARE YARD FOR OILING

Item	Min.	Max.	Aver.
Cleaning surface	0.0025	0.0050	0.00375
Hauling and distributing oil and sanding	0.0075	0.0125	0.0100
Cost of oil	0.0200	0.0400	0.0300
Cost of sand	0.0025	0.0075	0.0050
	0.0325	0.0650	0.04875

II. DUST SUPPRESSION ON GRAVEL AND MACADAM

The use of oils for dust suppression must not be confused with the construction of the bituminous wearing surface or carpet which will be described later. For dust laying, the object sought is to mitigate the disagreeable characteristics of the ordinary gravel or macadam road without attempting to use a type of oil or method of construction that will preserve the surface to any considerable degree.

Dust results from the wearing or loosening of particles of the road surface and from the grinding up of soil carried onto the surface from adjacent earth roads or streets. To this may be added droppings from horses, material that leaks from vehicles during the time it is being transported over the road, and a small amount of miscellaneous refuse of unclassified origin. The process of dust suppression does not contemplate the prevention of dust from these sources, but merely a treatment that will prevent it from blowing about. This is accomplished by periodical sprinkling with an oil that possesses sufficient binding power to hold the particles together and prevent them from being carried away by the wind. The bituminous materials suitable for this purpose have already been discussed in Chap. XVI.

As with earth surfaces, the gravel or macadam surface should be practically free from dust when the oil is applied, and should be smooth and true to cross-section. If repairs are necessary these should be made some weeks prior to oiling if possible so as to give the new material time to compact in place before being oiled.

The oil must be applied with more care than on earth roads because less will be absorbed and an excess will be disagreeable. One of the multiple-nozzle pressure distributors described in Chap. XVIII is best adapted for the work, and the oil or tar may be applied hot or cold, depending upon the grade used.

A first application usually consists of ½ gal. per square yard of surface, and subsequent applications of ¼ to ⅓ gal. per square yard. If, however, too long a time elapses between treatments, it would, of course, increase the quantity of oil needed. Two applications the first season and one each succeeding season usually suffice, but this also depends upon the character and amount of traffic and the nature of the surface.

It has been shown that repeated oiling will gradually render the surface impervious to water and cement the particles together to a limited degree, especially if a good grade of oil or tar is applied. On the other hand, there is some danger of introducing into the surface an oil that will act as a lubricant instead of as a binder, and in that event the road will become loose and rapidly develop pot holes and ruts under traffic. Considerable difficulty has been experienced throughout the United States from that source and too much emphasis cannot be put on the importance of using a good asphaltic base oil or a suitable grade of tar.

While it is desirable to cover the oil with a light dressing of coarse sand or screenings, it is possible to overdo the matter and thus offset to some extent the benefit of the oil. One cubic yard of the sand or screenings should cover at least 200 sq. yd of surface.

Light oils and tars are also used for the suppression of dust on broken stone roads and the general principles that have been discussed in connection with gravel roads apply to macadam roads as well. Since the macadam surface is hard to clean, it is advisable when possible to apply the oil before the surface becomes dusty. When a new road is put in service, traffic will gradually brush off most of the excess of screenings, and there will follow an interval when the surface is almost bare. Later the stone may begin to wear and produce more dust or the larger stones may loosen and work out on the surface. In either case the surface has gone beyond the proper stage for oiling. The oil or tar used on macadam surfaces is of the same character as is used on a gravel road and the method of application and quantity

varies in the same way. The use of greasy oil is even more detrimental to macadam than to gravel.

The oils and tars used for dust suppression on gravel and macadam surfaces range in price from 4 to 7 cts. per gallon and the cost of application varies from ½ to 2 cts. per gallon. The actual cost of oil treatments has generally been from 3 to 5 cts. per square yard of surface for each application.

Oil on Hard Pavements.—Light oils have been used to a limited extent on brick and concrete pavements for the suppression of dust, but definite conclusions as to the desirability of the practice have not been reached. It seems probable that where systematic flushing cannot be carried out, the oil may serve to palliate the dust nuisance. Emulsions of oil and water have also been employed to a limited extent with only small success.

Other Palliatives.—Many proprietary compounds have been advanced from time to time as dust preventatives. The most widely used have either been hygroscopic salts or semi-sticky byproducts soluble in water. These compounds are usually of only temporary effect and have not come into wide use.

Water is, of course, the most common form of palliative and needs no discussion in this connection. Water sprinkling must be kept up with great regularity in hot weather to be of benefit, and is the most expensive method of dust suppression, and at the same time one of the least effective.

BITUMINOUS CARPETS

Purpose.—A bituminous carpet serves several distinct purposes: (*a*) it prevents the formation of dust by attrition of the road surface; (*b*) it has a tendency to catch and hold dust carried onto the surface from external sources; (*c*) it forms a somewhat elastic cushion, thereby increasing the comfort of those who use the pavement; (*d*) it renders less noisy hard surfaces; (*e*) it takes the wear, thus preserving the material upon which it is placed; (*f*) it prevents the removal of the binder from a gravel or macadam surface by automobiles.

Requirements of Bituminous Material.—It is apparent that a thin layer of plastic material placed on top of a hard surface will be subjected to constant kneading from the rolling wheels and the hoofs of animals, which will work into it such inert material as may be deposited on the surface. The kneading will also have a tendency to shear the bituminous layer from the rigid

material under it and the constant addition of inert matter will gradually reduce the ability of the bituminous material to accommodate itself to the constant slight motion. Necessarily then, the bitumens used for "carpets" must be ductile and adhesive and must be of a staple and durable nature. The materials employed for this purpose are described in Chap. XVI.

The bituminous surface is used on gravel, broken stone, and to a limited extent on concrete roads and pavements. It was first adopted for use on macadam to prevent destruction by automobiles, but has been recognized for its value in the other

FIG. 71.—Cleaning a surface for carpet coating.

particulars mentioned and is now one of the standard maintenance methods for gravel and macadam roads.

The bituminous carpet is employed under two widely different conditions: (1) to a newly completed gravel or broken-stone macadam; (2) to a badly worn gravel or broken-stone macadam, or one that has been under traffic for some time. The purpose of the surfacing is the same in both cases, but the method of preparation is somewhat different.

Applying the Bituminous Carpet to a New Road.—Both the gravel and the macadam type of surface depend for their stability upon the binding properties of the finer material in the surface. This may be stone dust or silt and clay. It is not desired to

replace this binding material with the bituminous binder but rather to insure its retention in the surface. Accordingly roads that are to be surfaced with a bituminous material are finished as water-bound surfaces.

It is customary to finish these surfaces with some excess of binder, that is, with some fine material on the surface for reasons already explained (Chap. X). The bituminous material cannot be applied successfully to a dusty surface. Therefore, a newly constructed road is opened for traffic for a time to permit it to "season" or compact and to bring to attention any weak places that may have been overlooked during the construc-

FIG. 72.—Applying the oil for carpet coat.

tion. This may require only a few weeks if the traffic is heavy, or it may require several months. During this period the fine material will be gradually brushed and blown from the surface by traffic and eventually it will approach the proper condition for bituminous surfacing. The surface to be covered should have a close-knit texture, but be free of dust and loose chips or pebbles. The binder between the stones should be intact, but the surface itself should be clean and free of the screenings or other bonding material. There should be no ruts or depressions in the surface, or, if any have developed, they should be repaired. It is not usual to find the surface clean across its entire width, and the outer portion will usually require sweeping which may be done with a power machine or by hand.

When the surface is properly prepared the bituminous material is spread with the pressure distributor which is the only machine that can be successfully used for the work.

The quantity of bituminous material applied ranges from ⅓ gal. to ¾ gal. per square yard of surface, with ½ gal. as about the average treatment. If for any reason an excess of the bituminous material is used in spots, these places should be broomed to thin them out. With care and a good machine such instances will be rare. The best results are obtained when the material is spread out.

After the road has been covered, a thin layer of torpedo gravel or of stone chips is spread over the bituminous material. The

FIG. 73.—Spreading the oil with a brush.

success of the treatment depends very greatly on the class of material that is used to cover the bituminous coating. It must be apparent that the thin layer of plastic surface will be subjected to severe treatment and if soft screenings or chips are used they will grind up quickly and lose their value. Granite or trap or equally hard stone chips must be used. If a clean coarse torpedo sand is available it will be satisfactory, provided it is not too fine. A size passing a ½-in. screen and containing little material that will pass a ⅛-in. screen is about right. Chips may graded from ¾ in. or 1 in. down, but should contain no dust.

The chips or sand is applied sparingly, being spread on from piles alongside the road. Just enough should be used to prevent the bituminous material from picking up on the wheels of vehicles. It is difficult to judge beforehand just how much will be required and it is good practice to put on a light coating and open the

road for traffic and then to add more as the need becomes apparent. The surface should be rolled thoroughly to set the chips in the surface.

Since the bituminous carpet does not penetrate the surface appreciably, it depends for its stability upon adhering to the stones of the road. A greasy material or one lacking ductility is certain to give disappointment.

The surface produced will be black after a few weeks of use, will be ¼ to ⅜ in. thick and will be ductile and show the imprint of wheels or hoofs readily. Its life is variable but usually is about two seasons. The cost ranges from 3 to 6 cts. per square yard of surface exclusive of the cost of minor repairs to the surface.

Bituminous Carpets on Worn-gravel and Macadam Roads.—Many broken-stone and gravel roads were built before the advent of heavy motor traffic and these have sufficed until recent years. With the ever-changing routes of travel such roads are constantly becoming a part of a motor route and bituminous surfacing becomes necessary to eliminate the dust nuisance and to preserve the surface.

The first step in the preparation of such a road is to restore it to a true cross-section and an even surface. This is done by repairing the ruts and depressions in the manner explained in Chap. X. After this has been done it is well to permit traffic on the road for a time to try out the repairs and further consolidate the patches, it being well known that a road is effectively consolidated by the vehicles using it even though the roller has been used for the repair work.

The next step is to clean the surface of the accumulation of stone dust, clay and other detritus. This is a troublesome task, especially on the older roads. The clay is usually caked on the surface and has been forced down into the interstices between the stones. If soft stone has been used for the road there will be an excess of dust to deal with. Sometimes the larger pieces of stone have been badly fractured by the constant pounding of wheels and although the stone retains its form due to being confined in the road, it has become chalky. When this condition is encountered, proper cleaning becomes difficult if not impossible.

The road is first swept with a power broom, and mud or other material that has become caked on the surface is loosened with picks or shovels between trips with the broom. Material lodged

in slight depressions is swept off with hand brooms. If the road were very dusty it may be necessary to flush it with water to remove the fine film not easily swept off. Every precaution must be taken to insure that the road metal is entirely free from dust because the bituminous surface will not adhere if any dust is left. If it is found impossible to secure a clean surface, the attempt to place the bituminous carpet should be abandoned because it can not be successfully accomplished.

When the surface is properly cleaned, the bituminous material is spread and covered in the manner already described for new macadam or gravel roads.

FIG. 74.—Showing the effect of using an excess of oil.

The cost for surfacing is the same as for new roads but the cost of repairing and cleaning will vary widely as will be readily understood.

Bituminous carpets on gravel roads have never been very satisfactory and it is questionable practice to employ other than very fluid oils or tars for the purpose. It seems impossible to carry out the construction in any manner that will insure the resulting surface against peeling off.

Bituminous Carpets on Concrete Roads.—The bituminous carpet is applied to concrete roads and pavements for the reasons that have been mentioned in connection with gravel and macadam roads, except that there is no tendency for a concrete road to ravel under motor traffic. In addition to those reasons two

others are of moment. Concrete roads have a tendency to crack in an erratic manner and if the crack is unprotected the concrete breaks down along it and the deterioration that follows is difficult to repair. It is common practice to fill the crack and cover the surface along both sides of it with a bituminous material. Covering the entire surface obviates the necessity for constant watchfulness in repairing cracks.

On account of the hardness of the concrete pavement it suffers somewhat from abrasion of steel-tired vehicles and eventually a slight tendency for the smaller pieces of the aggregate to break

FIG. 75.—The motor driven oil distributor now widely used.

out is observed. A bituminous coating effectually prevents any considerable deterioration from this cause.

The concrete surface is cleaned by sweeping and washing so that every vestige of dust has been removed and the bituminous material is applied and covered with chips just as described for gravel and macadam surfaces.

The resulting surface is similar in every respect to the bituminous carpets already described.

No little difficulty is encountered in securing a material suitable for this work and the tendency for the carpet to peel off the concrete has never been entirely overcome.

EXAMPLE OF GOOD PRACTICE

I. Minnesota[1]

Conditions in Minnesota.—I shall now describe conditions as we have them in Minnesota and the methods used. Our bituminous surface treated roads may, in general, be divided into three classes:

(1) Those sections where the subsoil is a sand, the gravel surfacing is deficient in binder, as usually occurs in sandy areas. The more ¼- and ¾-in. stone in the gravel surface, the better the results.

(2) Compacted clay and gumbo subgrades which have been treated prior to a light application of gravel. The roads treated have either been located in sections where gravel surfacing had to be shipped in and is very expensive, or on certain gumbo subgrades which appear to eat up the gravel during wet periods. Minnesota does heavy grading in these sections, running 14,000 to 20,000 yd. per mile for a 30-ft. road. This brings the surface of the road from 4 to 5 ft. above the bottom of the ditch line and the ditches are usually quite wide. I do not believe our treatment of this class of roads would be successful if it were not for the high grade line which adds to the stability of the roadbed.

(3) The treatment of gravel surface roads on clay and loamy subgrades.

Treatment on Sandy Subsoil.—I will now discuss each class in more detail:

A typical analysis of the subgrade in the sandy area is as follows:

	Per Cent
Retained on 10-mesh sieve	0.5
An analysis of part passing No. 10 is as follows:	
Total sand	90.2
Total silt	5.5
Total clay	4.3
Cementing value	2.0

A typical analysis of the resurfacing used on this type is as follows:

[1] Lang, F. C., "Bituminous Treatments of Gravel Roads and Earth Subgrades" (Condensed), in *Roads and Streets*, Vol. 68, No. 5, p. 262, May, 1928.

	Per Cent
Passing 1 in. retained on No. 10	65.0
An analysis of part passing No. 10 is as follows:	
Total sand	95.0
Total silt	3.1
Total clay	1.9

Of course there are variations from this typical analysis. We have used both tar and asphaltic cut-back oils for these conditions. The number of miles of tar is 120.3. The number of miles of asphaltic cut-back oil is 1. We have been well satisfied with our tar treatments. The asphaltic cut-back oil is really an experimental piece. A typical analysis of the tar used is as follows:

Water	
Specific viscosity (Engler 50 cc. at 40°C.)	11.7
Total bitumen	97.41
Distillation:	
0—170°C	1.4
0—270°C	22.8
0—300°C	29.9
Softening point	44.2

A typical analysis of the asphaltic cut-back oil used on the 1-mile experimental piece is as follows:

Specific gravity	0.948
Flash	76°C.
Specific viscosity at 60°C	11.2
100 penetration residue	60.4
Ductility of residue	58
Loss at 163°C	13.0
Total bitumen (soluble in CS_2)	99.94
Total bitumen insoluble in 86° naphtha	17.43

The method of application is as follows:

The first operation consists of grading all of the loose material to the center of the road, thus forming a smooth hard surface. In only a few instances have we resorted to sweeping. The ideal road surface at the time of the first application should be smooth, well compacted, dry, and free from dust.

The second operation is the spraying of the prepared surface with about ¼ to ⅓ gal. of tar heated to about 130°F.

Third operation: After about 24 hr., or when the first application has completely penetrated and set up, the surface is again sprayed with ¼ to ⅓ gal. of tar, and at once covered by blading

the loose material previously removed on to the fresh tar. In case the bladed material contains an excess of fines of a non-granular nature, it is wasted over the shoulder, and suitable material for covering is windrowed on the opposite shoulder, bringing the total amount of covering material up to about 350 cu. yd. per mile. The best covering material is pea gravel (retained No. 10 passing $\frac{3}{8}$-in. screen), and where gravel plants are near this is used; usually, however, selected local deposits have been used.

Fourth operation: The opposite side of the roadway is then cleared with a grader, throwing the loose gravel into a windrow over the edge of the tar section and leaving the opposite side free for treating.

Fifth operation: The remaining side is treated with penetration coat and allowed to set up the same as the first side treated.

Sixth operation: This side is then treated with second coat of tar and loose graded material bladed in from side for cover the same as before.

Seventh operation: The roadway is dragged a number of times to smooth it and work all the gravel possible into the tar. This dragging operation is continued for a period of 3 to 5 days or until the surface has set up to such an extent that dragging does not do any good, or the surface at that time is in a hard condition. At this time, any small breaks or holes should be immediately patched with premixed material, using the same grade of tar and the same material as is used for the cover coat. If large holes develop, a coarser grade of road metal may be used to insure a more stable patch. At completion, the crown for a 30-ft. top would be from 6 to 9 in. This method is really a combination of the penetration and surface-mixing methods. Its success depends largely on penetration into compacted surface. We find this makes a good bond between the old roadbed and the surface, and we have had very little trouble with creeping of surface.

On this type of road the daily traffic varies between 700 and 1,500 vehicles per day. Initial cost for a 24-ft. surface ranges between $1,600 and $1,800 per mile. The cost of maintenance varies between $300 and $600 per year. One patrolman with occasional auxiliary equipment can successfully handle 20 mi. of this kind of road, taking care of the patching, cutting of grass, repairing washouts, etc.

Treatment on Compacted Clay and Gumbo Subgrades.—Of the second class (treated subgrades) we have 131 miles. The subgrades treated have been in the extreme southeastern and northwestern parts of the state. A typical analysis of the subgrade in southeastern Minnesota is as follows:

Passing No. 10 sieve	99.8 per cent
Total sand	1.5 per cent
Total silt	56.8 per cent
Total clay	41.7 per cent
Cementing value	135

A typical analysis of the gumbo soil in northwestern Minnesota is as follows:

	Per Cent
Passing No. 10 sieve	99.5
Total sand	8.6
Total silt	21.8
Total clay	69.6

In all of our subgrade treatments we have used a straight distillation mid-continent residuum. A typical analysis of the oil most used is as follows:

Specific gravity	1.044
Flash	164°C.
Specific viscosity at 60°C	12.9
100 penetration residue	65.2
Ductility of residue	100+
Loss at 163°C	2.8
Total bitumen (soluble in CS_2)	99.91
Total bitumen insoluble in 86° naphtha	16.23

The method of treatment is quite similar to the method just described for tar treatment. Considerable care is taken to see that the subgrade at the time of treatment is well compacted, smooth, free from dust, and dry. Weather conditions play a great part in the application of oil on this class of work. Warm weather aids the penetration of the oil into the subgrade, and rainy weather tends to slow up the work because it is hard to get the surface dried out sufficiently to allow a penetration into the grade far enough to get the depth desired.

About 400 cu. yd. of cover material per mile is used. The cover material as previously described is preferably pea gravel, but usually selected local deposits are used. The gravel takes the wear. Too much emphasis cannot be placed on having the surface of the road well above the water table.

Treatment of Gravel Surface on Clay and Loamy Subgrades.—In the third class of treatments, the gravel surface on clay and loamy subgrades, I am unable to give any typical analysis of the subsoil or gravel surfacing. Included in this class are the intermediate soils between sand and clay. The surfacing also varies, but, in general, where we have clay subgrades there is considerable clay binder in the gravel surfacing; however, it is not uniformly distributed. Belonging to this class of roads we have 21 miles of tar, 17 miles of asphaltic cut-back oil, and 96 miles of mid-continent residuum. The choice of bituminous material to use is made after an examination and analysis of the composition of the gravel surfacing and the subgrade, also taking into consideration the thickness of the compacted gravel surface. I am unable to give any definite figures on which the decision as to the class of bituminous material to use is finally made. In general, tar and asphaltic cut-back oils have been the most satisfactory on granular soils, and the straight run residuum on the heavy soils. The method of application is entirely similar to the method previously described for tar treatment on granular soils.

Keeping the Road in Service.—When necessary to use the road during time of construction, we endeavor to protect the motorist from temporary inconvenience in the following ways:

(1) We keep one-half of the road in such condition that traffic can go over it without getting into the freshly placed material.

(2) We place warning signs at the ends and along the section being treated, informing the motorist what to do.

(3) Patrolmen are placed at the ends to stop the motorist and tell him how to proceed.

At the same time we expect the cooperation of the public and there have been times when it has been necessary to have police power bestowed on patrolmen to enforce requirements, that is, in driving with unnecessary speed on freshly laid material.

Useful References

1. "Oil Treated Highways in Washington," *Public Construction News*, Vol. 6, No. 3, Feb. 10, 1928, p. 75.
2. "Sand-Asphalt Highway Construction in Delaware," *Contractors and Engineers Monthly*, Vol. 18, No. 1, January, 1929, p. 47.
3. Butler, J. T., "Bituminous Surface Treatments Surface Application Method," *American City*, Vol. 40, No. 9, February, 1929, p. 91.
4. James, E. W., "Oil Products Show Promise for Low-cost Road Building," *Manufacturers' Record*, Vol. 95, No. 6, Feb. 7, 1929, p. 95.

CHAPTER XVIII

PENETRATION AND MIXED MACADAM ROADS AND PAVEMENTS

I. PENETRATION MACADAM

The name *penetration macadam* is given to a type of construction in which a bituminous material is sprayed on the surface of a layer of stone that has been prepared in such a manner that the bituminous material will penetrate 1 or 2 in. into the layer, thereby serving as a binder to hold the mass together.

Bituminous macadam may be constructed by the penetration method with any of the kinds of stone that are used for the ordinary macadam. The methods of construction vary slightly with the character and size of the stone used, but the distinguishing characteristic is that the binder is poured onto the surface of the layer of stone and is expected to penetrate sufficiently to hold the surface together.

Design of Cross-section.—Since the penetration macadam does not possess any considerable flexural strength, it supports traffic loads by distributing the load over the subgrade to such an extent that the bearing power of the soil is not exceeded. In this respect the penetration macadam is analagous to the water-bound macadam. The design for any location is therefore based on engineering judgment and experience and an appraisal of the stability of the subgrade that will be encountered. The penetration surface is usually about $2\frac{1}{2}$ in. thick. The lower, or base courses, vary in thickness and number according to the nature of the subgrade and the kind of traffic.

When used on city streets, penetration macadam is ordinarily constructed between combined concrete curb and gutter.

The cross-slope most frequently adopted is an average of $\frac{1}{2}$ in. per foot of width.

Typical cross-sections for penetration macadam are shown in Fig. 76.

Foundation Course.—The foundation course may consist of Telford with a layer of water-bound macadam over it, or it may

consist of a layer of water-bound macadam placed directly on the subgrade. In either case the foundation course is rolled and bonded with screenings just as though it were a water-bound macadam. In many cases the penetration macadam is laid on an old water-bound macadam road that has had some years of use and requires resurfacing.

Sizes and Kinds of Stone.—Certain general principles governing the size of stone to use have been discussed in connection with water-bound macadam roads and these apply to penetration

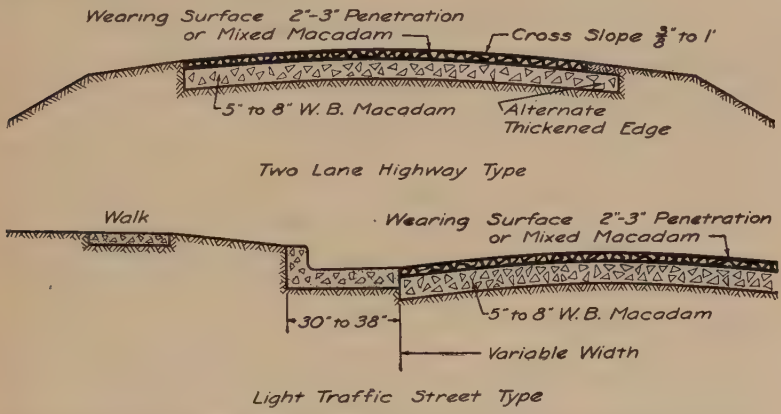


FIG. 76.—Typical cross sections for penetration or mixed macadam roads and streets.

macadam as well. The sizes commonly employed are summarized as follows:

A. Hard stone ranging in size from 1½ in. down to ½ in. Chips from the same kind of stone and ranging from ½ in. down but with the dust removed.

B. Medium stone ranging in size from 2½ in. down to 1 in. Chips screened through a ¾-in. screen and with the ¼ in. and finer removed.

C. Crusher-run stone of either hard or medium grade but containing no material passing a ¼-in. screen.

D. Stone of either of the above grades but screened to a fairly uniform size such as 2½ to 1½ or 1 in.

E. When chips of suitable hardness cannot be obtained, pebbles screened from hard gravel may be substituted. The size ranges from ½ in. down to ⅛ in.

It will be apparent that when rolled, Class *A* stone will give a surface having smaller openings for the bituminous material to penetrate than will Class *B* stone, and that Class *C* stone will

produce a surface with smaller voids than either Class *A* or Class *B*. It will also be seen that Class *D* will produce a more porous surface than Class *A* or *B* or *C*.

It is therefore desirable to apply the bituminous binder to Class *C* stone before any rolling is done and without spreading any chips prior to the application of the binder. Class *A* stone is rolled but no chips are spread before the binder is poured. Class *B* or *D* stone is rolled and the voids partially filled with chips before any binder is poured. Where Class *E* material is used it is substituted for chips and is handled in the same manner as chips.

Bituminous Binders.—Both tar and asphaltic binders are used for the penetration macadam and the general characteristics have been discussed in Chap. XVI.

Wearing Course.—After the foundation course has been completed, the stone for the upper course is spread to the required thickness. Whether or not it shall be rolled before the bituminous material is poured into it depends upon the size of the stone and the texture of the surface. If the surface appears to be fairly well filled with fine material, as would be the case with Class *C* stone, it would be so dense when rolled that the bituminous binder could not penetrate into it. Therefore, with such stone it is best to spread the bituminous binder before the surface is rolled.

Rolling.—It is desirable to have as great mechanical stability in the upper course as can be obtained and, therefore, it is better practice to use a coarse stone and roll the layer before the bituminous material is spread. If the stone has been rolled until the surface is closely knit together, there will be little danger of the finished road becoming rutted or uneven and the bituminous binder will hold the chips in place and thus maintain a close-knit texture in the surface.

Examination of the surface after it has been rolled will show it to be made up of angular pieces of stone closely packed together, between which are voids of various sizes, depending upon the size of the stone and the thoroughness of the rolling. If the voids are large, they must be partially filled with chips to prevent the bituminous binder from penetrating too deeply into the layer. Usually with stone of Classes *B* and *D* the application of chips at this stage of the construction is advisable, but with Class *A* stone the texture will be close enough without the chips.

When chips are used they are thinly spread over the surface from piles alongside and are brushed into the openings in the surface, any excess being brushed off at the edges. Care and persistence are necessary to secure an even texture in the surface and it can only be obtained if the chips are carefully spread and properly brushed into the surface.

The chips used must be of tough stone; otherwise, they will grind up rapidly under traffic because of their small size. If no hard, tough, chips are available, clean screened gravel of the proper size may be substituted.

Applying Bituminous Binder.—The bituminous material is spread at a temperature that will insure its being fluid, which may be anywhere from 250° to 450°F., depending upon the kind of material used. It may be spread by means of hand pouring cans, but this method is likely to result in a somewhat uneven distribution of the material.

The gravity type of distributing wagon is often used but it is also open to objection because of the variation in flow as the tank empties. The pressure-distributing wagon is best from all standpoints and is coming to be the standard apparatus for this class of construction.

The quantity of bituminous material that is used for the first application varies from 1 to 1½ gal. per square yard of surface. It is desirable to secure a penetration of about 1 in. and to coat all of the stones that show at the surface. Here again care must be exercised to secure uniformity.

After the first spreading of the binder, the surface is covered with chips which are brushed into the remaining voids in the surface and rolled lightly. The second application of binder then follows, the amount used being about ¾ gal. per square yard of surface. It is covered with chips and rolled. In some instances a third application of about ½ gal. of binder is used which is covered with coarse sand or chips and rolled.

MACHINERY AND APPLIANCES USED FOR BITUMINOUS MACADAM CONSTRUCTION

Pouring Cans.—Bituminous materials are sometimes spread on road surfaces by means of hand pouring cans which are much like a garden watering pot except that the spout is larger and the nozzle is a slot instead of a perforated disc. In some types of cans the slot is horizontal and in others vertical, the latter being

preferable. It is also an advantage if the width of the slot is adjustable so as to help control the rate of flow of material.

Gravity Distributing Wagons.—Wagons of this kind are used for spreading bituminous materials on road surfaces either for

FIG. 77.—Pressure distributors for penetration macadam construction.

penetration construction, carpeting, or dust laying. As the name indicates, the bituminous material flows from the tank by gravity and is, consequently, somewhat variable in amount, depending upon the height of material in the tank. The dis-

tributing devices or nozzles are of many types but in the essential consist of a pipe supported about 1 ft. above the road surface and having circular openings or slots for the material to flow through. The pipe is suspended from the rear of the tank and is slightly longer than the tread of the wagon. A control valve is attached to the delivery pipe in most wagons of this kind and many of them are equipped with fire boxes so that the contents of the wagon may be heated.

Pressure Distributors with Multiple Spray.—In order to provide for accurate control of the quantity of material being distributed and to force it into the minute openings in the road surface, pressure distributors have come into extensive use. In general design they are similar to the gravity distributor except that air or steam pressure is applied to the tank so as to force the material out of the nozzles at a high velocity. The distributing devices usually consist of a series of small nozzles screwed into a pipe which is suspended across the rear of the wagon about 6 in. from the road surface. In some machines of this type the pressure is obtained by pumping the hot material out of the tank and forcing it through the nozzles.

In recent years many elaborate motor-driven distributors have been placed on the market and these have a wide range of capacities. For surfacing country roads, the motor-truck type is very much to be preferred to the horse drawn because of the saving in time effected in getting the material from the railroad siding to the road. The sprays are of many designs and the pressure is sometimes obtained by pumping the binder and sometimes by pumping air into the tank.

These motor distributors are well adapted to the purpose for which they are used. The quantity of the bituminous material that is used can be controlled within very narrow limits.

II. MIXED BITUMINOUS MACADAM

Mixed bituminous macadam is a road surface consisting of crusher-run stone or of gravel, cemented together by means of a bituminous binder. The materials are hot-mixed and the mineral aggregate is selected and graded in such a way as to secure reasonable density in the surface. In appearance the finished mixed macadam resembles the penetration macadam very closely, and the cross-section employed is like that shown for the penetration type except that the surface layer is mixed

instead of being built up by the penetration method. Typical cross-sections for mixed macadam are shown in Fig. 76.

Stone for Mixed Macadam.—Crusher-run stone with the dust removed, or mixtures of stone and sand are employed for the mixed macadam. The principles that are observed in selecting the proper size of stone for the penetration macadam are also applied to the selection of stone for the mixed macadam. If medium or soft stone is to be used a larger size is required than if a hard and tough stone is available. Quite generally, the crusher-run stone with the dust removed is employed. It is apparent that stone alone will have a high percentage of large voids and the essential difference between the hot-mixed macadam and asphaltic concrete is in the care with which the aggregate for asphaltic concrete is selected to secure a low percentage of voids.

It will be recalled that in the discussion of penetration macadam attention was directed to the use of crusher-run stone and the difficulties of securing penetration of the bituminous material. The mixed macadam was developed to overcome that difficulty and yet secure the advantages of the better grading obtained by the use of crusher-run stone instead of screened stone.

Foundation.—The mixed macadam is placed on top of an old water-bound macadam or gravel road or upon a newly constructed base of water-bound macadam or gravel. The necessity for a rigid foundation course has been frequently referred to in connection with the other types of construction and is equally important for the mixed macadam. If an old macadam or gravel road is used for a foundation, it must be brought to a true surface parallel to that prescribed for the finished road and enough below it to permit placing a uniform surface layer of the requisite thickness.

When a new macadam base is constructed for this surface it is built exactly in the same manner as the base for the penetration macadam.

Wearing Surface.—The bituminous cement and the stone or gravel are heated separately and then mixed either by hand or in a mixer of a type resembling the concrete mixer. The amount of binder used is from 15 to 20 gal. per cubic yard of stone.

The hand-mixing method has little to recommend it except that but small expense is entailed for equipment, which is a factor to consider on small work.

The portable type of hot mixer which is drawn along the road as work progresses is frequently employed and is satisfactory although somewhat limited in capacity. Figure 78 shows mixers suitable for this work.

The permanent or semi-permanent plant located near the stone supply is also frequently employed and is the most economical

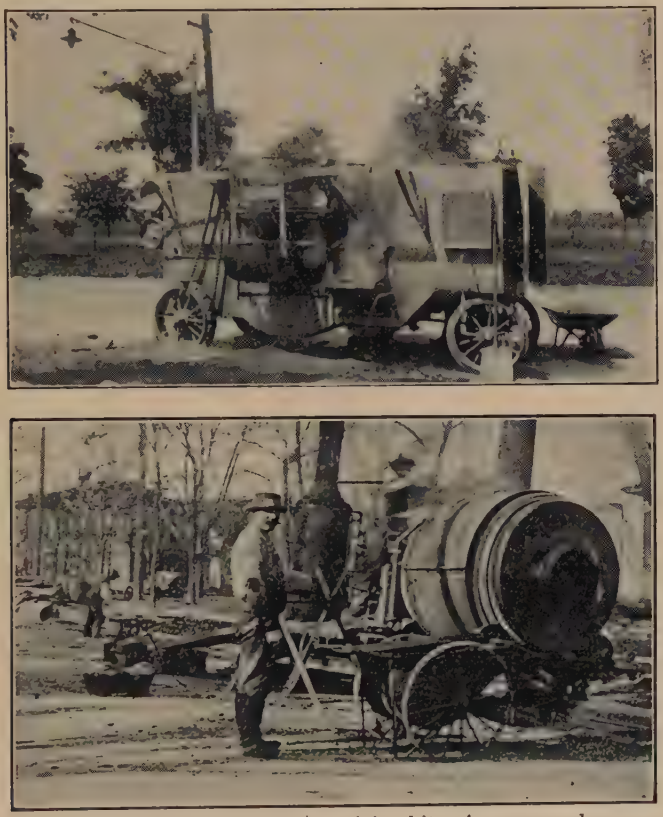


FIG. 78.—Portable plants for mixing bituminous macadam.

in operation. The distance that the mixture can be hauled must be considered and this will often necessitate the use of the portable plant for rural highway surfacing.

The mixture is prepared at a temperature of about 200°F., and must be spread at a temperature of not less than about 150°F. These temperatures vary somewhat with the kind of bituminous binder used, as would be expected.

The mixture is conveyed to the road in dump carts or in motor trucks and is dumped on metal platforms from which it is shoveled into place in the road, and raked to the required thickness, including an allowance for compression during rolling.

The rolling is accomplished with a tandem or three-wheeled roller weighing about 8 tons, and is continued until the surface is thoroughly compacted. The roller moves parallel to the edge of the road as in rolling water-bound macadam, and the operation proceeds in much the same way.

After the surface has been properly compacted it is covered with a thin coating of the bituminous material applied as a seal coat. The quantity required for the seal coat varies from ⅓ to ½ gal. per square yard of surface, the seal coat being spread over the surface with a fiber broom or with a squeegee.

The surface is finally covered with a light dressing of stone chips ¾ in. in size and free from dust, or of pea-size gravel, and is rolled just enough to bed the dressing in the seal coat.

The mixed macadam surface varies in cost between $1.25 and $2 per square yard, exclusive of the base course.

Its characteristics are in general similar to those of penetration macadam except that it is more uniform in texture and consequently more durable. It is not widely used, but has passed the experimental stage and its construction is well standardized.

Oil Mix Macadam.—A modification of the hot-mixed macadam has been developed in California[1] and the results so far secured indicate that the process has considerable merit and a rather wide field of usefulness. It may be used as a resurfacing for a worn macadam or a new surface may be constructed by the process.

If used for resurfacing, about 2 in. of the old macadam surface is loosened by scarifying and the loose material distributed with a blade grader so as to restore the cross-section of the worn road. The surface is again scarified to insure a fairly uniform layer of loose material. The surface is then ready for the application of the oil binder which is a medium fuel oil from asphaltic base petroleum and is liquid at ordinary air temperature.

The oil is applied from a pressure distributor and the layer of stone immediately harrowed with a disc harrow. Oiling and harrowing are repeated until the stone has the proper coating

[1] STANTON, T. E., "The Oil Mix Method," *California Highways and Public Works*, November, 1927, p. 12.

which is determined largely by the appearance of the mass. When the harrowing is satisfactorily completed the stone is graded into a ridge along the middle of the road and then graded back and forth to complete the coating of the stone. The mixture is then spread over the road with the blade grader and is ready for traffic. During the first few days of use the surface is kept smooth by using a light blade grader.

Such a surface requires from 2 to 7 per cent of bitumen or an average of ½ gal. of oil per square yard, and the exact treatment must be judged largely by the appearance of the mass. It is as yet too early to predict the service life of this type but it is easily scarified and retreated when that becomes necessary.

SPECIAL APPLIANCES

Sand and Stone Heaters.—These usually consist of a furnace around which a metal hopper is built. The material to be heated is thrown into the top of the hopper and when heated is shoveled out at the bottom. Sometimes the heater consists merely of metal pipe about 2 ft. in diameter which is laid on the ground and covered with the sand or stone. A fire is built inside the pipe and as the material becomes hot enough for use it is shoveled away and a new supply placed around the pipes. The more recent portable plants have a rotary drum drier and heater incorporated in the machine.

Melting Tanks.—Melting tanks are made in a great variety of shapes and capacities but all are designed on the same general principle. The outfit consists of a comparatively large furnace over which is mounted a tank for the material. The furnace will burn fuel oil, coal, or wood. The capacity varies from a 50-gal. kettle to a 500-gal. tank. In the larger sizes, a barrel rack is sometimes mounted above the kettle and enclosed in a sheet-iron case. The kettle is partly filled with the cold material and the rack is filled with barrels, open end down. The heat from the kettle gradually softens the material in the barrels so that it will flow down into the kettle to replace the hot material as it is drawn off. The tanks are mounted on wheels so as to be easily portable.

Mixers.—The portable type of hot mixer is used. In design it is very similar to the concrete mixer except that the drum is jacketed leaving a space between the mixer drum and the jacket through which the hot gases from the furnace are forced by

means of a fan. The materials are heated before they are placed in the mixer and it is only necessary to have the drum hot enough to maintain the temperature.

PRACTICE IN GREAT BRITAIN[1]

Surface tarring has been applied in Great Britain with advantage to old road surfaces in good condition and to new surfaces which are thoroughly consolidated and dried. The practice is to scrape or brush old road surfaces during the spring months and make good any pot-holes, grooves, waves or depressions, and then to apply the tar by automatic sprayer or by hand, depending on the available labor. This work is now done chiefly by hand, partly on account of the unemployment situation and partly because some road engineers favor the hand method as giving more satisfactory results.

The old road is half or totally closed to traffic before tarring begins and the surface is thoroughly cleansed of caked mud; the sides are strengthened if they have worn thin and, if the road is to be entirely resurfaced, stone chippings are used to bind in preference to fine material.

The tar used, unless it is a proprietary brand, conforms to one or other of the Roads Department (Ministry of Transport) Specifications. These are known as Tar No. 1, and Tar No. 2.

Specifications of Tar No. 1.—This tar was heated to a temperature which will insure that it reaches the road in a highly fluid condition; a boiler specially designed to prevent frothing is employed. The desired temperature in practice is usually found to be between 220 and 240°F.

This tar is derived wholly from the carbonization of bituminous coal except that it may contain not more than 10 per cent of its volume (or distillates or pitch therefrom) produced in the manufacture of carburetted water gas. The specific gravity at 59°F. is as nearly as possible 1.19, but must not be lower than 1.16 or higher than 1.22.

It is laid down by the Roads Department that the tar must not contain more than 1 per cent by volume of water or ammoniacal liquor, which must not contain more ammonia, free or combined, than corresponds to 5 gr. of ammonia per gallon of tar.

[1] *Eng. News-Record*, Oct. 5, 1922.

The amount of water or liquor is determined by condensation from the products of distillation of the tar by cooling with a cold water condenser. Any water so condensed is, after measurement, separated from any light oils present, and the amount of ammonia estimated by direct titration with acid.

On distillation in a liter fractionating flask one-half or two-thirds filled, to conform with the official specification, the tar should yield by weight the proportions of distillates given below:

(*a*) Below 338°F., not more than 1 per cent distillate (light oils), exclusive of water.

(*b*) Between 338 and 518°F. not less than 16 per cent and not more than 26 per cent of distillate (middle oils).

(*c*) Between 518 and 572°F., not less than 3 and not more than 10 per cent of distillate (heavy oils).

The total distillate between 338 and 572°F. must not be less than 24 per cent and not more than 34 per cent *i.e.*, where the middle oils approach the maximum allowed the heavy oils should approach the minimum, and *vice versa.*

The distillate between 338 and 518°F. (middle oils) must remain clear and free from solid matter, such as crystals of naphthalene, etc., when maintained at a temperature of 110°F. for half an hour. This requirement may be waived in the case of tar supplied direct from gas works, but tar from which naphthalene has been extracted is preferred to tar in which this constituent is excessive.

The middle oils should not yield to caustic soda solution more crude tar acids (phenol) than 3 per cent by volume of the tar.

The tar should not contain less than 12 or more than 21 per cent by weight of free carbon. This is determined by a complete extraction of the bituminous matter by benzol and bisulphide of carbon; the residue is taken as being free carbon.

Specification of Tar No. 2.—This tar is also heated to a highly fluid condition, which has been found to be between 260 and 280°F. For the preparation of tar macadam, the tar does not generally require heating to so high a temperature as for surface tarring; the necessary temperature being determined largely by the sensible heat of the stone treated by the tar, and also by the method of application.

This tar is derived from the same source as No. 1 except that it may contain up to 25 per cent by volume (or distillates or pitch therefrom) produced in the manufacture of carburetted

water gas. The specific gravity at 59°F. should be as nearly as possible 1.21, but not less than 1.19 or higher than 1.24.

As regards fractionation, the requirements below 338°F. are the same as for Tar No. 1. Between 338 and 518°F. not less than 12 and not more than 18 per cent of middle oils should be distilled; and between 518 and 572°F. not less than 6 per cent and not more than 10 per cent of heavy oils should be yielded.

In the naphthalene, phenol, and free carbon tests, the distillate should remain clear for half an hour at 100°F.; the middle oils should not yield more than 2 per cent phenols by volume; and the weight of free carbon should not be less than 12 or more than 22 per cent.

Tar-surfacing Methods.—Either of these tars may be used, but if the heavier grade is employed the surface is always allowed to become well warmed by the sun's rays before application. Where hand methods are employed flexible pipes are used to convey the tar from the boiler to the road. As an alternative to these pipes, which are manipulated by hand, 3-gal. pouring cans, with the orifice 1½ in. in diameter and the spout leading direct from the can bottom, are utilized.

As a general rule, in the case of roads tar-treated for the first time, the amount used is 1 gal. to every 5 or 7 sq. yd. Gritting, if necessary to allow traffic to pass, is delayed as long as possible, and the material used is stone chippings, crushed gravel, coarse sand, or other material free from dust, which must pass a ¼-in. mesh.

On heavily trafficked roads a second coat is applied, either over the whole surface or from 9 to 12 ft. in the road center to the extent of 1 gal. of tar per 8 to 10 sq. yd. This is done 2 to 3 mo. after the first application.

Two or more samples of the tar used are kept in quart tin cans and labelled, showing the locality of application as well as the specification. The Roads Department has arranged with the National Physical Laboratory to submit a selection of samples to chemical and physical test for the benefit of road engineers.

Careful records are kept of the road condition in the various seasons, both before and after tarring, and such records show the quality of the tar used, the area covered, the state of the weather during tarring operations, time occupied in these operations, number of men employed, and full details of material and labor costs.

Surfacing with Tar Macadam.—Before laying a tar-macadam surface, trial trenches are opened at intervals of 450 ft., extending from the road haunch to the center and on alternate sides of the road, so as to ascertain the thickness of the old crust and the state of the foundation.

The thickness of surface coating after consolidation by rolling is as near 3 in. as possible; if a coat thicker than 3 in. is to be laid, the material is applied in two separate coats.

In the case of naturally hard subsoils, not materially softened by infiltration of surface water, the total thickness of the road crust including foundation, if any, is not less than 6 in. after consolidation by rolling. If the subsoil is hard enough to form a good foundation in itself, this thickness is reduced to 4 in. If a clay or other yielding subsoil is located, the thickness exceeds 11 in.

As a rule the crossfall on the finished surface is about 1 in 32. If the crust is not sufficiently thick at the crown to enable this crossfall to be obtained with a new coating of the above thickness, then the old surface is left intact and unscarified, and the new coat made as thick as necessary. If the crust is sufficiently thick the regulation of the crossfall is obtained by scarifying the surface and removing material from the crown to the sides previous to the application of the new coat. The material so loosened is screened and any material finer than ½ in. is discarded.

The broken stone or slag used for aggregate is made up of 60 per cent 2-in. standard gage; 30 per cent 1½-in. standard gage; and 10 per cent ¾- to ½-in. size stone for filling voids during rolling operations.

In the case of two-coated work the subcrust consists of 2-in. standard gage stone, and the wearing surface 1½-in. standard gage stone; 10 per cent of ¾- to ½-in. size stone is then used for void-filling.

The stone is thoroughly dried before coating and, if Tar No. 1 is used, especially in hot weather, the tarred material is allowed to stand long enough for the tarred stone surfaces to become partially hardened and "tacky." If Tar No. 2 is employed, the macadam is laid soon after tarring, and preferably when the road is quite dry and in warm sunny weather.

The amount of tar used per ton of stone, varies from 9 to 12 gal., according to the stone sizes, the grade of tar and the method of mixing.

In most cases a 10-ton roller is employed to finish off the work of an 8-ton roller since less rolling is required than in the case of water-bound macadam.

It has been found advisable to apply a coating of tar to the macadam surface after several weeks' passage of traffic, to the extent of 1 gal. of tar per 6 sq. yd. This tar is usually No. 2 and is sprayed on at a temperature of 270°F.

Surfacing with Pitch-grouted Macadam.—As in the case of tar-macadam surfacing, the road is opened up every 450 ft. to ascertain the thickness of the old crust and the state of the foundation.

The thickness of the pitch-grouted macadam coat is usually 2 in. on very lightly trafficked roads, and from 2½ to 3 in. on others for single pitch-grouting, and from 4 to 4½ in. for double pitch-grouting.

The thickness of the road crust is made the same as for tar-macadam roads, *i.e.*, 6 in., 4 in., and 11 in. under similar conditions. The crossfall and the methods of obtaining it are also the same as for tar-macadam roads.

The material for pitch-grouting is broken to 1½ in. standard gage. In addition to this, 10 per cent of chippings of the same stone, varying from ⅜ to ¾ in., is used for closing after grouting with the melted pitch. The pitch employed usually complies with the Roads Department specification as follows, the viscosity being modified to suit climatic and local conditions by varying the quantity of tar oils:

Specification for Pitch.—The pitch is obtained of the required consistency by running it off from tar stills in which the distillation of tar has been stopped at a point at which the residual pitch will give a penetration of 70 when tested at 77°F. on a standard penetrometer. Harder pitch is softened or cut back so as to secure this penetration by the addition of tar oils which are preferably a filtered green or anthracene oil, wholly derived from tar produced by carbonization of bituminous coal or from such tar mixed with not more than 25 per cent of its volume of tar produced in the manufacture of carburetted water gas.

The specific gravity of these oils at 68°F. is between 1.065 and 1.085, and they are free from solid matter such as naphthalene and anthracene after standing for half an hour at 68°F.

These tar oils must be commercially free from light oils and water, and must yield at:

(*a*) Below 338°F. not more than 1 per cent light oils and water.

(*b*) Below 518°F. not more than 30 per cent middle oils.

(*c*) Below 626°F. not less than 95 per cent heavy oils, middle oils, and light oils and water, if any.

The pitch is not poured unless the stones are quite dry, which is affected by tarpaulin protection or by the employment of portable blowers. When the material is spread and levelled, it is rolled down dry without chippings until the stones present a mosaic surface.

The quantity of pitch required to grout a single coating is about 1¼ gal. per square yard for a consolidated thickness of 2 in., 1½ gal. for 2½ in., and 2 gal. for 3 in.

In melting the pitch, boilers of from 2 to 3 tons capacity are charged with pitch and about one-half of the proper proportion of tar oils. The fire is kept bright until the pitch reaches a temperature of 300°F. after 4 or 5 hr., the other half of the tar oils is then added and the mixture thoroughly stirred. During this heating the fire doors are kept closed. After stirring, the doors are opened and the mixture allowed to fall to 250 or 270°F. If bad weather interferes, the fire door is left open, the damper closed and the mixture allowed to fall to 200°F., at which temperature it is maintained at a consumption of about 7 lb. coke per hour. The boiler is always kept airtight during the melting of the pitch.

The sand used, which is clean and sharp, is heated to 400°F. Mixture, in equal parts of sand and pitch, is effected in a separate vessel called a "dandy," and poured into pouring cans of 2 to 3 gal. capacity. During the whole time the matrix (sand and pitch) is continually stirred.

Final rolling is begun immediately after pouring and pushed forward before the matrix has had time to set. The 10 per cent of graded chippings is spread partly before and partly during rollings. Traffic is allowed to pass as soon as the surface has cooled to the normal temperature.

Where the traffic is heavy enough to demand double pitch-grouting, the bottom layer is made the thicker and consists of large stones, the two layers being rolled down and grouted separately. The stone for the bottom layer is graded from 2 to 3 in. standard gage, and no chippings are used for finishing the rolling of the bottom coat. The stone for the top layer is 1½ in. gage, and is finished with chippings graded from ½ to ¼ in.

So as to provide a key for the top layer the pitch is poured until about ½ in. of the stones is left exposed. The pitch used for double pitch-grouting is 3¼ gal. per square yard, with a thickness of 4 in., and 3½ gal. for 4½ in., though these quantities are sometimes varied for different materials.

Problems

1. An existing water-bound macadam averages 14 ft. wide, 7 in. thick, and has about 4 in. of crown. It is desired to convert it into an ample two-lane penetration macadam to accommodate increasing traffic. Design the cross-section for the reconstruction.
2. A real estate development, an addition to a small city, has been promoted and the streets are to be paved with mixed macadam to serve until the area builds up. Design the cross-section for the pavement.
3. Write a specification for all of the materials to be used for a penetration macadam pavement for a road that is used only by automobiles and light delivery trucks.
4. An old concrete-paved street in a residential district is to be resurfaced with mixed bituminous macadam. Describe each of the materials you would recommend for the new construction. Be sufficiently explicit so that a street commissioner would be able to purchase, exactly, the materials you suggest.

Useful References

1. Goldbeck, A. T., "The Bituminous Macadam Pavement," *Bull.* 6, The National Crushed Stone Association, October, 1928.
2. Mayer, J. H., "Asphaltic Limestone Surface on Old Gravel Roads," *Public Works*, Vol. 60, No. 1, January, 1929, p. 41.
3. "Surface-mixed Asphalt Cuts Construction Costs," *Construction Methods*, Vol. 11, No. 1, January, 1929, p. 66.
4. Stevens, E. F., "20-mile Slag Tar-macadam Road in Australia," *American City*, Vol. 40, No. 1, January, 1929, p. 94.
5. Bowman, C. H., "Oil Mix Method of Treating Gravel Roads," *Pacific Street and Road Builder*, Vol. 23, No. 6, December, 1928, p. 32.

CHAPTER XIX

SHEET ASPHALT AND ASPHALTIC CONCRETE SURFACES

I. SHEET ASPHALT

The asphalt pavement in its modern form was first laid in Paris about the year 1858 followed by the laying of a pavement in London in 1869 and one in New York in 1870 or 1872. These pavements were constructed with a wearing surface of Val de Travers natural rock asphalt from Switzerland.[1]

The first asphalt pavement constructed with prepared mixtures was laid in Washington D. C. in 1876.[2]

From these beginnings the asphalt pavement, as known today, was developed. By the application of the method of trial and error, mixtures were evolved to meet the needs of traffic until the heavy truck began to be the critical load. It was then learned that still further modifications in the mixture were needed to insure stability under the severest traffic, and laboratory research and field experimentation are being carried out to that end. These have not as yet progressed beyond the preliminary stage.

Meanwhile, there exists ample technical information to enable the engineer to design asphalt pavements that are adequate for all ordinary traffic conditions.

The sheet asphalt pavement consists of three layers or courses; a foundation course, a binder course, and a wearing course. The wearing course consists of a bituminous mortar composed of fine sand, finely ground mineral filler, and asphalt cement, and it is this layer that gives to the pavement its name, although it is not easy to explain how the name originated. A typical cross-section for a sheet asphalt pavement is given in Fig. 79.

Design of Cross-section.—The foundation course gives the flexural strength to the asphalt pavement and the first problem in the design of the cross-section is to design the foundation. The procedure outlined for the design of concrete road slabs is followed if the concrete foundation is to be used.

[1] ABRAHAM, HERBERT, "Asphalts and Allied Substances," 2nd. Ed., 1920, pp. 16, 17, 116, D. Van Nostrand Co.

[2] *Ibid.*, p. 16.

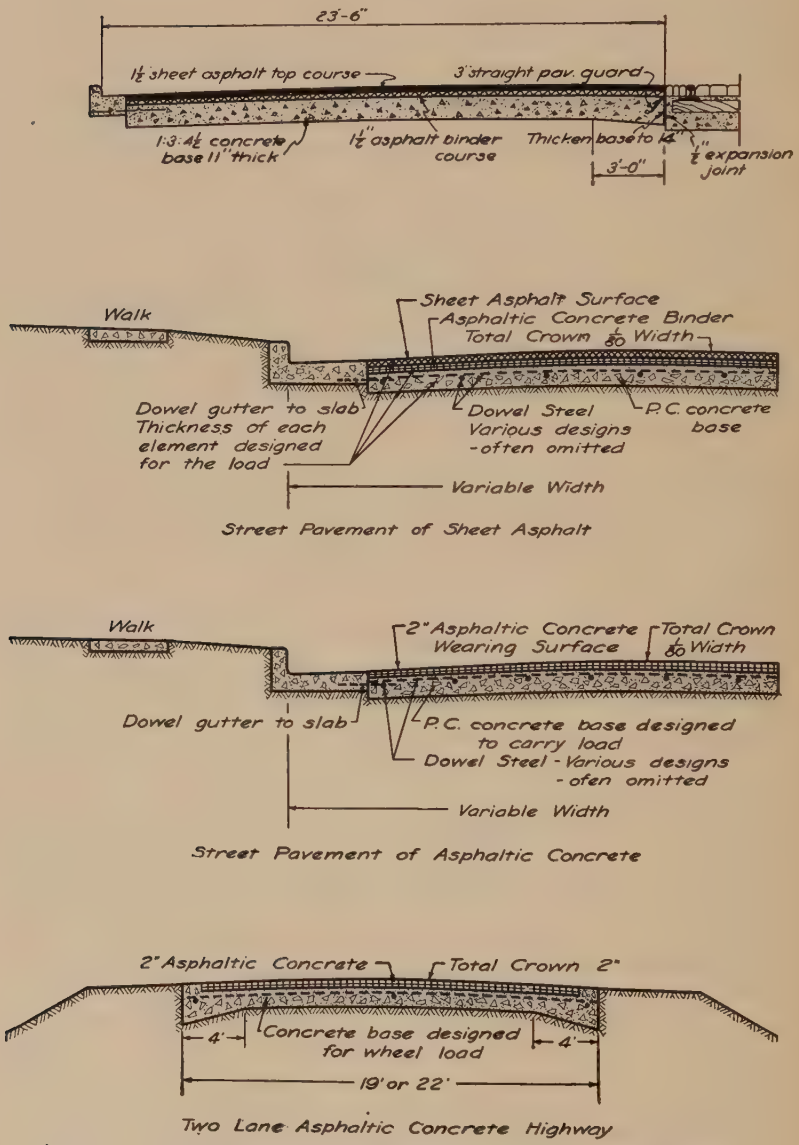


FIG. 79.—Typical cross sections for sheet asphalt and asphaltic concrete.

The equivalent static load is determined as in previous cases and no allowance is made for a reduction in the ordinary impact allowance because of the asphalt surface.[1] It is further assumed that the asphalt surface does not add to the flexural strength of the pavement.[2]

If the base course is of some material other than concrete, the thickness adopted is based on the designer's estimate of the supporting power of the subgrade material and the probable stability of the base course he proposes to use. Such foundation courses are principally of value in affording a good explanation for the failure of the pavement. They should be adopted only under conditions known, beyond doubt, to be favorable.

The sheet asphalt surface is slightly plastic in cool weather and markedly so in hot weather. It must be adequately supported if it is to give normal service. There is some doubt whether the design of the sheet asphalt pavement has kept pace with the growth of traffic loads, and this excellent type of surface has failed in cases where the fault was obviously in the foundation more frequently than where the fault could be attributed to inadequacies of the asphalt surface.

Foundation.—To a very large extent the concrete foundation has superseded all other types for new sheet asphalt pavements. It will doubtless become more and more the standard foundation for sheet pavements and, when properly designed and constructed, can be depended upon to support adequately the wearing surface.

Past practice has been to use concrete of such proportions as, 1 part cement, 3 parts of fine aggregate, and 6 parts of coarse aggregate (1:3:6); or, 1 part cement, 2½ parts fine aggregate, and 5 parts coarse aggregate (1:2½:5). As actually laid, these proportions produced concrete with a flexural modulus of rupture varying from about 100 lb. per square inch to about 300 lb. per square inch.

At the risk of tiresome reiteration, attention is once more directed to the fact that the determination of the proper mixture for the concrete in the foundation course is a problem in design, the thickness of the foundation varying with the strength of the

[1] TELLER, L. W., "Impact Tests on Concrete Pavement Slabs," *Public Roads*, Vol. 5, No. 2, April, 1924, p. 1.

[2] "Static Load Tests on Pavement Slabs," *Public Roads*, Vol. 5, No. 9, November, 1924, p. 1.

concrete. It must be attacked with a view to producing a concrete base of the proper strength at the lowest possible cost. The exact proportions will depend not only upon the strength needed, but also upon the relative cost of the constituent materials at a specific location.

The requirements for the quality of the concrete materials are those usually specified for high-grade concrete, save only that no great consideration is given to the wearing quality of the coarse aggregate.

The concrete foundation should be finished accurately to grade, being regularly tested with a straight-edge and templates if need be, so that the asphalt top will be of reasonably uniform thickness. The base need not be float-finished, but it should have a surface free from protruding stone or areas deficient in mortar. A reasonably uniform mortar surface is about the ideal to strive for. Artificial roughening is sometimes resorted to, but is generally considered unnecessary.

Black Base.—There has been a relatively limited use of asphaltic concrete and asphaltic macadam for the foundation of the sheet asphalt pavement, and a few examples of very good construction may be found where this type of base was employed. Probably the slowness with which this design has been accepted may be attributed in part to a lack of well-substantiated data upon which the base design may be predicated. Little enough is known with regard to the behavior of the concrete base but even less is known as to the probable load-carrying capacity of the black base. As a consequence, precedent must be accepted as the chief guide in the design, extreme care being exercised to make sure the loads and the subgrade soil are within the limits permissible for this type.

The thickness of the black base has varied in past construction from 2½ in. on some California work, to 6 in. on some Middle Western jobs, but the general experience seems to show that 4 in. of good asphaltic concrete is needed on residence streets where favorable soil conditions exist, and that 6 in. will be required for mixed traffic streets in the same location. Where the typical soils of the humid areas of the United States compose the subgrade, 6 in. would be about the minimum thickness to consider for the black base, even on light traffic streets. The present state of knowledge of the strength of black base does not warrant using it for streets that carry loads in excess of about 3 tons.

The black base has its greatest economy in connection with the resurfacing of gravel or water-bound macadam where it is necessary to increase somewhat the strength of the existing surface in order to convert it into a satisfactory base before placing the wearing surface. In many such cases, 3 or 4 in. of the base mixture will suffice.

The binder course is omitted when sheet asphalt is placed on the asphaltic concrete base.

Water-bound Macadam Foundation.—Water-bound macadam has been used to a limited extent as the base for sheet asphalt, but it is much more common to use asphaltic concrete for the wearing course that is to be placed on macadam.

If constructed new for the purpose, the macadam base is designed and constructed in exactly the same manner as the wearing course of a water-bound macadam roadway surface. If an old macadam road is utilized for base, it is repaired in the same manner as a macadam roadway surface that is being restored. Possibly a few inches of black base would be added to strengthen the macadam.

If the sheet asphalt is laid without a black base over the macadam, the usual binder course would be supplied.

Gravel Foundation.—Gravel is rarely used for the foundation for sheet asphalt except in connection with the black base, and probably, should never be used except in that way.

Worn Block Pavements for Foundations.—Sheet asphalt is admirably adapted for resurfacing brick, stone block, or concrete pavements that have worn until they are too rough for satisfactory service. The larger depressions in the old pavement are repaired with concrete and the smaller ones filled with the binder mixture. The binder course is then laid and the pavement is completed in the usual manner.

Binder Course

Originally the sheet asphalt wearing surface was placed directly on the base, but it was found to creep and become uneven, and the intermediate or binder course was accordingly introduced. The binder course consists of a layer of asphaltic concrete placed directly on top of the concrete base. The thickness of the binder course depends upon the class of traffic and the total thickness of wearing surface that it necessitates. For heavy-traffic streets the binder course is usually 1½ in. thick, while for residence or

other light-traffic streets 1 in. is sufficient. For streets carrying traffic made up of very heavy individual loads, it is recommended that the binder be 2 in. thick.

The binder mixture is of two types, known respectively as open binder and close binder, the difference being in the grading of the mineral aggregates.

Open Binder.—The open binder is composed of stone ranging in size from ¼ or ½ in. to 1 in., to which is added from 5 to 8 per cent of asphalt cement. If the stone does not carry some fine material such as will pass the No. 4 sieve, from 10 to 15 per cent of ordinary concrete sand may be added. Other size limits for stone are sometimes specified, but in this type of binder no attempt is made to secure a dense mixture, nor are the voids filled with the asphalt cement as is apparent from the proportions given. The asphalt cement must be sufficient in quantity to coat all the stones so that when rolled the binder will be well cemented together. The surface of the binder course after it is rolled will be porous and open; hence, the designation that is given it. The surface interstices of the binder course will be filled with the surface by the rolling.

Close Binder.—Close binder differs from open binder in that the mineral aggregate is graded so as to secure a fairly dense mixture in which the large voids are fairly well filled. This is accomplished by mixing broken stone and sand in such proportions that the sand will fill the voids in the stone. The stone ranges in size from 1 in. down, and crusher-run is frequently employed. The sand should be well graded, but the requirements are not so rigid as those for sheet asphalt surface mixtures. The following specification is typical of those used for the close binder.[1]

[1] Specification Alabama State Highway Department, 1927, *Pamphlet E*, p. 28:

"The constituents of the binder course shall be combined in such proportion as to produce a mixture conforming to the following composition, by weight:

Passing 1-in. circular screen and retained on ½-in. circular screen	15	to 50 per cent
Passing ½-in. circular screen and retained on 10-in. sieve	30	to 65 per cent
Passing a 10-mesh sieve	15	to 35 per cent
Bitumen	4.5	to 7 per cent

The proportions shall be varied between the limits specified as directed by the Engineer."

The amount of asphalt cement required for the close binder is somewhat greater than that required for the open binder.

The close binder is recommended for streets carrying moderate or heavy traffic, and the open binder is permissible only on very light-traffic residence streets.

Character of Materials for Binder Course.—The stone for the binder course must transmit the load from the wearing surface to the concrete base, but since the medium is somewhat plastic the requirements for the stone are not exceedingly rigid. Any hard tough limestone, trap rock, or granite may be used. The stone should be clean and should run with reasonable uniformity as to grading. The sand for the close binder should be of the quality and cleanness required for high-class concrete. Gravel pebbles are sometimes used for coarse aggregate in close binder.

Old Surface Mixtures for Binder.—Old sheet asphalt surfaces that have been removed in resurfacing streets are occasionally utilized for the preparation of close binder. The old surface mixture is melted in kettles heated by steam and then mixed with the proper amount of stone. Additional asphalt cement is added to renew the life of that which is in the old surface mixture. Suitable precautions must be taken to insure that the old mixture is thoroughly broken up and distributed through the mass of stone and that the right amount of new asphalt cement is added. The asphalt cement in the ordinary binder course is of the same quality as that used for the surface mixture except that it can advantageously be about 10 points softer.

Surface Mixture

The surface mixture for the sheet asphalt pavement consists of sand, filler, and asphalt cement.

Sand.—It has long been recognized that the stability of the sheet asphalt surface depends to a large extent upon the gradation of the mineral aggregate. Experience with cement mortars has shown the importance of using a sand that is properly graded, to insure density and strength, and the sand grading is no less important in the sheet asphalt surface mixture. In as much as the mineral aggregate comprises about 90 per cent of the volume of the surface, it is reasonable to expect that it needs to be carefully selected and properly graded. The sand should be clean and free of slate, shale, or other friable material. It is generally thought that sharp sand is better than sand made up of rounded

particles, but this cannot be stated as a general fact because successes and failures have been recorded with both classes of sand.

It does appear to be established that asphalt cement adheres more readily to some types of sands, particularly those that have grains with a rough surface, than to those with polished grains. Laboratory tests will indicate which sands are preferable and will also serve to check the stability of various mixtures of sand and filler. The laboratory should be utilized more generally for this sort of study than seems to be the practice at present.

Filler.—The filler is the portion of the mineral aggregate passing the 200-mesh screen, and may consist of finely ground rock dust or of portland cement. The filler plays an important part in the mixture, since it serves to fill the small voids and to give density to the surface. A good filler should not only be fine enough to pass the 200-mesh sieve, but also contain a good percentage of particles that will pass a 400- and also a 600-mesh sieve. Since sieves are not made commercially with more than 200 meshes per inch, the amount of the finer particles is estimated by a modification of the method of elutriation which is employed in soil analysis. Portland cement is a desirable filler since it is finely ground and is made up of very durable particles. It is more expensive than limestone dust and for that reason the stone dust is often used. Limestone dust ground to the proper degree of fineness is widely used for filler, and while it is possibly less stable than portland cement, it is satisfactory. Silica dust is also employed for filler and seems to be as good as portland cement. In the preparation of stone dust for the filler the stone is first heated so as to thoroughly dry it and then crushed and finally ground in a ball mill using flint pebbles for the abrasive. Some grinding mills use steel rollers for grinding but the resulting product is usually not as finely ground as that produced in the ball mill. The filler should be ground to such a fineness that at least 70 per cent will pass the 200-mesh sieve and 95 per cent will pass the 100-mesh sieve.

Theory of Proportioning.—Most of the sheet asphalt gradings that have been used in the past were developed by trial, and the mixtures employed in any city were usually adopted after the various sands available to contractors at that place had been examined and perhaps used on a few contracts. The proportion-

ing was largely a matter of hit or miss, there having been no theoretical basis established.

In recent years some important researches[1] have been conducted with a view to establishing a correct basis of universal application for proportioning asphalt mixtures and considerable progress has been made in that direction.

At the present time there are really two schools of thought with reference to proportioning; one is that the mineral aggregate should be so graded that a low percentage of voids will be obtained (a theory that was current 20 years ago and later abandoned) and that the asphalt cement serves to fill the voids; consequently, the quantity of asphalt cement to use will depend primarily upon the void content of the mineral aggregate.[2] The other theory is that the asphalt cement serves to coat the particles of the mineral aggregate and, therefore, the quantity of asphalt cement required will vary with the total surface area of the aggregates. According to this idea, the greater the quantity of fine material in the mixture, the greater the quantity of asphalt cement that will be required, which checks out only fairly well in practice.

It is impossible at this time to produce conclusive evidence in support of either theory, although there are strong indications that the void theory possesses considerable merit if the correct interpretation of the void test can be found.

Meanwhile, it is necessary for the engineer to rely to a considerable extent upon the old empirical standard gradings as a basis for proportioning asphalt mixtures. This he may do with considerable assurance, as is attested by the enormous yardage of good sheet asphalt that is laid each year.

A mixture of sand and filler may be designed to give a low percentage of voids, but whether the mixture as laid actually as a low percentage of voids will depend upon whether it is a workable mix. If it is too tough and dry, the rakers will not be able to spread it quickly, and, consequently, will not comb it thoroughly, and if they fail to do so, the mixture will not be uniform in texture or thickness after rolling. The hot asphalt cement serves as a lubricant to the particles of sand during the rolling, and dry

[1] HUBBARD, PREVOST, and F. C. FIELD, "Researches on Asphalt Pavements," *Circ.* 34, The Asphalt Association, New York, N. Y., 1926.

[2] SKIDMORE, HUGH W., "Sheet Asphalt Mixture Research," *Engineering and Contracting* (*Roads and Streets*), Vol. 63, No. 4, April, 1925, p. 693.

harsh mixtures will not compact to the theoretical density because of lack of mobility. The standard gradings afford a good starting place in the design of mixtures and were the basis of most of the gradings in use in 1928.[1]

Established Gradings.—The sand gradings shown in Table XVII are widely used for sheet asphalt surface mixtures. They have been well established in practice and the nearer the surface mixture approaches these in composition, the more likely the pavement will be to having the desired stability. It will be noted that the various sizes are separated into three groups, and while it is desirable to have the specified amount of each

TABLE XVII.—STANDARD SAND GRADINGS[2]

Sieves	Heavy traffic, per cent		Light traffic, per cent	
Passing 10-mesh, retained on 20-mesh	5		10	
Passing 20-mesh, retained on 30-mesh	8	23	10	35
Passing 30-mesh, retained on 40-mesh	10		15	
Passing 40-mesh, retained on 50-mesh	13		15	
Passing 50-mesh, retained on 80-mesh	30	43	30	45
Passing 80-mesh, retained on 100-mesh	17		10	
Passing 100-mesh, retained on 200-mesh	17	34	10	20
Passing 200-mesh	0		0	
	100		100	

SPECIFICATIONS FOR SAND GRADING

Passing 10-mesh	....	100
Total passing 10-mesh, retained on 40-mesh	....	12–50
Passing 10-mesh, retained on 20-mesh	2–15	
Passing 20-mesh, retained on 30-mesh	5–15	
Passing 30-mesh, retained on 40-mesh	5–25	
Passing 40-mesh, retained on 50-mesh	5–30	
Passing 50-mesh, retained on 80-mesh	5–40	
Total passing 80-mesh, retained on 200-mesh	....	20–40
Passing 80-mesh, retained on 10-mesh	6–20	
Passing 100–mesh, retained on 200–mesh	10–25	
Passing 200-mesh	0–5	

[1] SMITH, FRANCIS P., "Construction of Hot Mix Pavements," *Canadian Engineer*, Vol. 32, No. 2, Jan. 11, 1927, p. 132.

[2] Sheet Asphalt, Brochure 9, 3rd Ed., The Asphalt Association, New York, N. Y.

size, it is not always possible to secure sands so graded. If each group is present in the right amount, that is usually the best that can be accomplished. These gradings must be relied upon unless laboratory studies of the materials to be used indicate desirable modifications.

The finer portion of the mixture is the most important and the grading may more safely depart from the standard as regards the material above the 40-mesh size than as regards the material finer than the 40-mesh. The amount of filler that can be used in a mixture depends upon the amount of fine sand present. The trend of present-day practice is toward the use of 18 per cent, or more, of filler. An analysis of a sheet asphalt mixture that has successfully withstood heavy traffic for a number of years is given in Table XVIII. This mixture is typical of good practice.

TABLE XVIII.—ANALYSIS OF A TYPICAL SHEET ASPHALT MIXTURE[1]

Bitumen	10.6	
Passing 200-mesh sieve	18.3	45.5
Passing 100-mesh, retained on 200-mesh	16.5	
Passing 80-mesh, retained on 100-mesh	10.7	
Passing 50-mesh, retained on 80-mesh	22.8	30.2
Passing 40-mesh, retained on 50-mesh	7.4	
Passing 30-mesh, retained on 40-mesh	3.6	13.7
Passing 10-mesh, retained on 30-mesh	9.3	
Retained on 10-mesh sieve	0.8	
	100.0	

[1] From the author's files.

Asphalt Cement Required.—The amount of asphalt cement required for the mixtures provided for in Table XVII will vary between 9 and 13 per cent of the total mixture including the asphalt. There is no basis other than the pat test and visual inspection based on long experience for determining the exact amount of asphalt to use. In the laboratory, preliminary tests may serve to indicate the approximate amount of asphalt cement required, but the mixtures produced at the asphalt plant will seldom be exactly like the laboratory samples. Hence, the quantity of asphalt cement must be determined for the run of the plant on the basis of the pat test, supplemented by stability tests on samples taken from the pavement after the mixture has been rolled. Fortunately, small variations in the quantity of

asphalt show up plainly in the appearance of the mixture and in the stain produced by the pat test.

The Pat Test.—A small wooden paddle with a blade 3 or 4 in. wide, 5 or 6 in. long, and ½ in. thick, tapered to an edge at one end and with a convenient handle at the other, is used to take as much of the hot mixture from the wagon as it will hold, being careful to avoid any of the last droppings from the mixer which may not be entirely representative of the average mixture. Samples of mixture should never be taken from the mixer itself, but only from the wagon after mixing is completed.

In the meantime, a piece of brown Manila paper with a fairly smooth surface, 10 to 12 in. wide, and torn off at the same length from a roll of this paper, which can be had at any paper warehouse, is creased down the middle and opened out on some very firm and smooth surface of wood, not stone or metal as this would conduct the heat too rapidly. The hot mixture is dropped into the paper sideways from the paddle and half of the paper is doubled over on it. The mixture is then pressed down flat with a block of wood of convenient size until the pat is about ½ in. thick.

The paper will be found to be stained to a different degree depending upon whether there is a deficiency, a proper amount or an excess present.

In this the amount of asphalt cement to use in making a mixture can readily be regulated, and the pat papers obtained will be evidence of the character of the mixture turned out. Where a laboratory examination is to be undertaken, a sample of surface mixture which is made from the material compressed between the paper can be used for this purpose, trimming it down into the proper form and sending it, accompanied by the paper, for the purpose.

Proportioning Asphalt Cement.—The proportion of asphalt cement is determined by weight. Since it is desired to use enough bitumen to coat all the particles, it is apparent that a more rational method would be to proportion the asphalt cement by volume. As a matter of convenience and accuracy, however, weighing is resorted to. The weight of asphalt cement per unit of volume varies considerably, and if the proportioning is by weight, account must be taken of the variation in the specific gravities of the asphalt cements that might be used. Attention is also called to the fact that the percentage of bitumen is always

specified, not the percentage of asphaltic cement. This is necessary because of the differences in the proportion of bitumen in the various asphalt cements. In determining the amount of asphalt cement to use it is, therefore, necessary to take account of the specific gravity and bitumen content of the cement.

To illustrate the significance of these facts in proportioning the asphalt cement in a paving mixture, consider a sheet asphalt surface mixture in which the percentage of bitumen by weight is 8.9. Assume that Trinidad Lake asphalt cement was used in which the percentage of bitumen is 65 and the specific gravity 1.28. The percentage by weight of asphalt cement necessary to give 8.9 per cent of bitumen is $8.9/0.65 = 13.5$ per cent.

If, however, an asphalt cement produced from petroleum were used the percentage of bitumen in the asphalt cement would be about 99.5 and the specific gravity about 1.03. The percentage of the asphalt cement required by weight would be substantially the same as the percentage of bitumen.

Since the bitumens extracted from the various asphalt cements vary somewhat in specific gravity, a proportion based on weight is not exactly a constant proportion by volume. This is the reason for the variation in the allowable percentage of bitumen provided for in the specifications.

Construction of the Pavement

The concrete base is finished and ample time is allowed for the concrete to set before the binder course is placed. If the binder is hauled too soon, injury to the base will result due to the weight of the trucks used for hauling. The base should be clean and dry when the binder is spread.

The binder course is mixed in the twin-pug type of mixer which is also used for mixing asphaltic concrete. The stone must not be too hot or some of the asphalt cement will run off while the mixture is being hauled; it must not be too cold or it cannot be spread and rolled satisfactorily. For most materials 275 to 325°F. is about the permissible range of temperature, but this is subject to some variation for the different asphalt cements.

The binder is dumped on the concrete in advance of the place where it is to be spread and is shoveled into place and raked to a thickness that will, when rolled, give the prescribed thickness of binder course. Experienced rakers need no guide in this operation and usually no guide is employed except possibly a line on

the curb at the top of the layer. A check on the average thickness is obtained by computing the area each load should cover to the prescribed thickness. Since the mixture is proportioned by weight, the weight per load is known.

As soon as spread, the binder is rolled, first with a 3-ton tandem roller and later by one weighing 8 to 10 tons. The rolling must proceed rapidly so that compression is secured before the asphalt cement cools too much. The rolling is carried out both crosswise and longitudinally and is a vital part of the construction, especially as regards the evenness of the finished surface. Only a skilled operator can be expected to secure satisfactory results.

FIG. 80.—Spreading sheet asphalt mixture.

The wearing course must be placed soon after the binder course has been rolled. It is especially desirable that close binder be covered with the wearing course the same day it has been laid, and it is safer to follow the same rule for all classes of sheet asphalt construction.

The mixture for the surface is prepared by weighing the sand, filler, and asphalt cement into a twin-pug mixer and thoroughly combining the ingredients by mixing. The temperature should be somewhat higher than for the binder material. With many kinds of asphalt cements a temperature of 350°F. may be reached without injury to the materials. Other asphalts must be handled at a somewhat lower temperature.

The surface mixture is hauled to the work in trucks and is dumped on metal or wooden platforms or on the binder course,

at a distance from the point of laying that will necessitate the entire load being shoveled into placed. When shoveled into place the mixture is thoroughly broken up with the rakes and is spread to the proper thickness for rolling.

Mechanical spreaders are coming into use, and when they are employed, the mixture is spread to approximate thickness by hand or by a spreader attached to the rear of the truck. The mixture is then raked and spread to exact thickness by mechanical methods.

The rolling begins as soon as possible after the spreading, the first compression being secured by means of a light tandem roller and final compression by means of the 8- or 10-ton tandem roller.

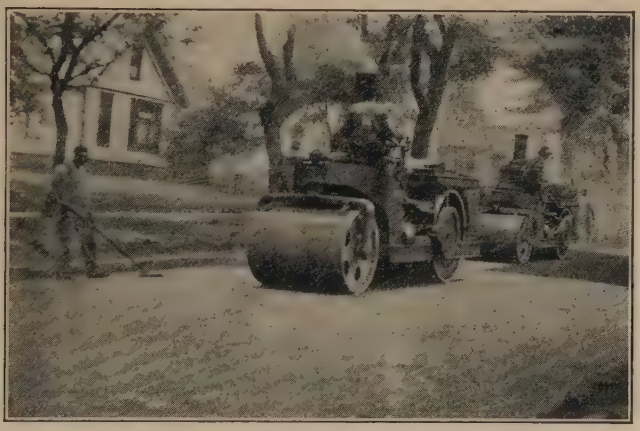


FIG. 81.—Rolling sheet asphalt surface.

Here again the character and uniformity of the surface will depend to a considerable extent upon the skill of the roller operator. A uniformly smooth surface will result if the rolling is properly done and unevenness is inevitable otherwise. Figure 80 shows the method of spreading the surface mixture and Fig. 81 the rolling.

The surface is sometimes dressed lightly with cement or stone dust prior to the final rolling, although the necessity of this is a mooted point. For the average sheet asphalt mixture about 110 lb. of the mixture is required per square yard of surface and, as with binder, the thickness is insured by computing the area each load should cover and requiring the load to be spread in that area.

Smoothness.—To secure the required smoothness of surface the accuracy of the spreading is checked by means of a straightedge applied to the surface parallel to the center line at various distances from the curb. As the rolling progresses, the checking is continued and low areas are brought up by patches while high areas that will not roll down are cut out and replaced. A good deal of the unevenness that develops in sheet asphalt surfaces is attributable to uneven spreading and rolling and to lack of uniformity in the mixture itself. Areas with an excess of asphalt cement are quite likely to become noticeable depressions in a short time after the pavement is placed in service.

FIG. 82.—Sheet asphalt surface destroyed by concentrated traffic.

Some Features of Design.—If a street has sufficient longitudinal slope to insure that no water will stand along the curb, the straight concrete or stone-block curb may be used, but if the slope of the gutter is less than 0.5 per cent, it is better to design the street with the combined concrete curb and gutter, or with a straight curb and block gutter.

It is undesirable to use sheet asphalt on a street where vehicles continually stand along the curb unless that portion of the street is paved with blocks of some kind. Wood-block, concrete, and grouted vitrified-brick surfaces are used for that part of the roadway.

The maximum grade for which the sheet asphalt surface is permissible depends upon the kind of vehicles that use the surface. Instances of sheet asphalt surfaces on grades up to 8 per cent have been noted and no especial difficulty is reported.

Where street-car tracks occupy the middle portion of the street there is a decided tendency for traffic to concentrate on the strip of pavement between the track and the curb, especially if the track paving is rough or noisy. This can be overcome to some extent by paving the car-track area with sheet asphalt or wooden blocks. Where traffic concentrates on the sheet asphalt,

FIG. 83.—Results of use of poor asphalt and improperly graded sand.

creeping and unevenness quickly develops and the pavement wears out very rapidly (see Fig. 82).

Characteristics of the Sheet Asphalt Surface.—The sheet asphalt surface is compared with other pavements in another chapter. It is desired here to call attention to certain characteristics that are inherent. Sheet asphalt requires a certain amount of traffic to keep the asphalt "alive." It is noticeable that on light-traffic streets the part of the pavement next the curb becomes granular and sometimes cracks badly, while the middle portion is kept in good condition by the action of traffic. Sheet asphalt also deteriorates rapidly under concentrated truck traffic such as may be expected on a narrow street with a busy double-track car line.

Asphalt Block Pavements

The asphalt-block pavement surface is constructed of blocks of a mixture similar to that used for sheet asphalt, compressed by very heavy pressure. Since the blocks are made in a specially equipped factory, all of the details of manufacture are subject to close control and the proportions of the various ingredients and the quality of the materials can be determined accurately. The product is, therefore, likely to be uniform. The blocks are formed under much greater pressure than can be secured in rolling a sheet asphalt surface and consequently they have greater density than does the average sheet surface.

Composition of the Blocks.—Asphalt blocks are composed of graded crushed stone or sand, filler, and asphalt cement. A typical specification provides as follows:

Sieve Sizes	Per Cent
Retained on ¼-in. sieve, round opening	Not more than 3
Passing ¼-in. sieve and retained on 20-mesh	35 to 60
Passing 20-mesh sieve and retained on 100-mesh	15 to 30
Passing 100-mesh (including all fines)	20 to 35
Passing 200-mesh sieve	Not less than 15
Bitumen	6.5 to 9.0

Size of Blocks.—The blocks are made either 2, 2½, or 3 in. thick and are 12 in. long and 5 in. wide. The 2-in. thick block is the one most widely used and is suitable for all ordinary locations. A variation of ¼ in. from the specified size is permitted. The blocks are formed under a pressure ranging from 240,000 to 360,000 lb. per block.

Subgrade.—The earth subgrade is prepared in the same manner as for the other types of pavement. This has been previously described.

Foundation.—The asphalt-block pavement is laid on a base of either gravel, macadam, or concrete, each type being constructed in the manner already described.

Bedding Course.—The bedding course is generally a layer of sand 1 or 2 in. thick which is placed in the same manner as for the other types of block pavement.

Laying the Blocks.—The blocks are laid on the sand cushion in regular courses at right angles to the center line of the street with the joints broken by a lap of at least 4 in. Each block is driven against the course already laid by means of a heavy maul so as to give close transverse joints, and the end joints are

tightened by means of a lever from the end of the course. The surface is covered with fine sand (passing a 20-mesh sieve). A

(*a*)

(*b*)

FIG. 84.—Showing defective sheet asphalt surfaces. In (*a*) the asphalt pavement is too soft and in (*b*) it is too hard. (Views about one-half natural size.)

plank or an iron plate is then placed over several courses and the blocks are rammed to place by tamping through the medium of the plank or metal plate.

II. ASPHALTIC CONCRETE

Asphaltic concrete, or bituminous concrete, is the name given to a type of roadway surface in which the mineral aggregate consists of graded stone, graded sand, and filler, and the binding agent of asphalt cement. Asphaltic concrete receives its name from the analogy between its composition and that of portland-cement concrete.

This type of wearing course developed after the sheet-asphalt type had come into general use and is in reality a mixture in which stone ranging in size from 1 in. down to ¼ in. is cemented together with a bituminous mortar identical with the sheet-asphalt surface mixture.

FIG. 85.—Laying asphaltic concrete.

The asphaltic-concrete surface mixture is placed directly on the foundation, there being no intermediate or binder course such as is used with sheet asphalt. One exception might be mentioned in this connection. A binder course is sometimes used with the Topeka type of asphaltic concrete, in reality this type is not asphaltic concrete, but might more properly be called stone-filled sheet asphalt, and it is often so designated. A typical cross-section for asphaltic concrete is shown in Fig. 79.

Stone.—The stone to be used in asphaltic concrete should be some durable type such as the better varieties of trap, granite, or the very best limestone. This is necessary because the individual pieces are bedded in a slightly plastic mortar and will crush under the heavier wheel loads unless the pieces are tough and sound.

Gravel pebbles have been used to a limited extent for the coarse aggregate in asphaltic concrete, and, frequently, a small amount of gravel is added to the broken stone to lower the cost of the coarse aggregate. Generally it is fairly safe to use gravel for the portion of the aggregate below the ¾-in. screen, but it is not certain that this is good practice when traffic loads are heavy.

There have been many failures of asphaltic concrete where soft limestone was used for the coarse aggregate, or where limestone of an absorbent character was used; that is, limestone that would not pass the soundness test. Where materials of this character were employed, failure occurred through the disintegration of the individual pieces of stone from traffic effects or the effects of repeated freezing.

Sand.—The sand should be of the same character as that recommended for sheet asphalt, and it should satisfy the sieve analysis requirements discussed in connection with sheet asphalt.

Filler.—The filler is also identical with that usually employed for sheet asphalt; *viz.*, portland cement or limestone dust.

Types of Asphaltic Concrete.—There are three types of asphaltic concrete, known as coarse-graded asphaltic concrete, Warrenite-Bitulithic, and Topeka asphaltic concrete, respectively. The coarse-aggregate type is what was formerly known as bitulithic, although the exact mixture used differs slightly from the old bitulithic formula. Warrenite-Bitulithic is the successor to the old bitulithic type, and is a patented pavement, the con-

COARSE-GRADED AGGREGATE TYPE OF ASPHALTIC CONCRETE[1]

	PER CENT BY WEIGHT	
The mixture consists of the following:		
Coarse aggregate (stone) passing 1-in., retained on ¾-in	15–45	55–65
Coarse aggregate (stone and gravel) passing ¾-in., retained on ¼-in	15–45	
Fine aggregate (sand) passing ¼-in., retained on 200-mesh sieve	23–35	
Filler passing 200-mesh sieve	4 to 8	
Bitumen	7 to 9	
The fine aggregate should be graded as follows:		
Passing ¼-in. screen	100	
Passing ¼-in. screen, retained on 10-mesh	0–20	
Passing 10-mesh sieve, retained on 40-mesh	25–50	
Passing 40-mesh sieve, retained on 80-mesh	30–65	
Passing 80-mesh sieve, retained on 200-mesh	15–40	
Passing a 200-mesh sieve	0–5	

[1] Specifications of the Asphalt Association, New York.

struction of which is licensed by Warren Brothers Company of Boston.

Warrenite-Bitulithic.—The Warrenite-Bitulithic type is made up of two layers; the lower one consisting of 1½ in. of substantially the same mixture as the coarse-graded aggregate type, and the upper one a layer of about ½ in. of sheet-asphalt mixture carrying a slight excess of bitumen. It is essential to this type that the two layers be spread one on the other, and then rolled to weld them together.

TABLE XIX.—SIEVE ANALYSIS OF TYPICAL WARRENITE-BITULITHIC MIXTURES

Sieve sizes	Sample number, percentage			
	1	2	3	4
Bitumen	8.40	6.33	5.62	7.10
Passing 200-mesh	6.22	4.45[1]	2.15[1]	5.80
Passing 80, retained on 200-mesh	11.26	9.65[1]	9.95[1]	10.80
Passing 40, retained on 80-mesh	12.48	11.80	13.96	14.62
Passing 10, retained on 40-mesh	5.60	4.82	6.15	6.00
Passing 4, retained on 10-mesh	9.92	9.70	7.65	10.54
Passing ½ in., retained on 4-mesh	13.54	19.85	20.29	15.34
Passing ¾ in., retained on ½ in.	10.40	13.05	12.41	14.48
Passing 1¼ in., retained on ¾ in	22.18	20.35	25.82	15.32

[1] Indicates a deficiency in that size.

The standard formula for Topeka asphaltic concrete is given in Table XX.

TABLE XX.—SHOWING TOPEKA GRADING

	PER CENT
Bitumen	7 to 11
Mineral aggregate passing 200-mesh	5 to 11
Mineral aggregate passing 40-mesh	18 to 30
Mineral aggregate passing 10-mesh	25 to 55
Mineral aggregate passing 4-mesh	8 to 22
Mineral aggregate passing 2-mesh	Not over 10

(Sieves to be used in the order named)

It will be noted that a wide variation in the grading is possible under the above specification, especially in the finer portions of the mixture, and it has, therefore, been found advisable to provide a closer grading for the sand in this class of pavement. In effect, the Topeka type of surface is sheet asphalt plus a

limited amount of stone not greater than ½ in. in size. The analyses of Topeka asphaltic concrete mixtures given in Table XX illustrate the care that ordinarily is taken in grading the sand. To secure a good Topeka-type mixture it is merely necessary to provide a heavy traffic sheet-asphalt sand and then add to it the desired amount of stone and the correct amount of asphalt cement to bind the whole together.

TABLE XXI.—SIEVE ANALYSIS OF TYPICAL TOPEKA MIXTURES

Sieve sizes	Sample number, percentage			
	1	2	3	4
Bitumen	8.00	6.0	10.0	7.0
Passing 200-mesh	15.6	10.4[1]	11.9	8.9[1]
Passing 100, retained on 200-mesh	13.3	14.5	11.1	9.7[1]
Passing 80, retained on 100-mesh	10.0	10.8	10.6	10.1
Passing 40, retained on 80-mesh	18.3	23.0	24.5	23.0
Passing 20, retained on 40-mesh	11.4	12.7	9.7	11.3
Passing 10, retained on 20-mesh	8.6	10.8	5.3	8.7
Passing 4, retained on 10-mesh	7.4	6.8[1]	8.0	9.7
Passing ½, retained on 4-mesh	7.4[1]	5.0[1]	8.9	11.6

[1] Indicates a deficiency in that size.

Foundation for Asphaltic Concrete.—Asphaltic concrete is laid on a portland-cement concrete foundation as a general rule, but is also laid on macadam base, on a black base, and sometimes is used to resurface old gravel roads. The requirements for these several types of foundation have been discussed in connection with the construction of sheet-asphalt pavements and need not be repeated, since the general principles apply equally to asphaltic-concrete pavements. If the portland-cement concrete is adopted, it is of the same composition and thickness as for the sheet-asphalt pavement. It is thought that the Topeka type of asphaltic concrete is likely to creep on a concrete foundation if the concrete is given a smooth finish. It is therefore customary to finish the surface of the foundation by tamping and to avoid striking or troweling in any manner. Some engineers require that the surface be finished with a knobbed tamper so as to leave pits in the surface. These are satisfactory except that they are difficult to clean when the base is swept preparatory to laying the wearing surface.

Sometimes the surface of the base is roughened by scattering coarse (1½ to 2 in.) stones over the green concrete and tamping them until half bedded in the base. This produces a good bond but decreases the effective thickness of the wearing course.

In other instances, the base is roughened by sweeping the mortar from around the stone just before the cement takes final set. If this work is carefully done the corners of the stone will be exposed and will form a good anchorage for the wearing surface. Everything considered, this is probably the most satisfactory method of roughening the base.

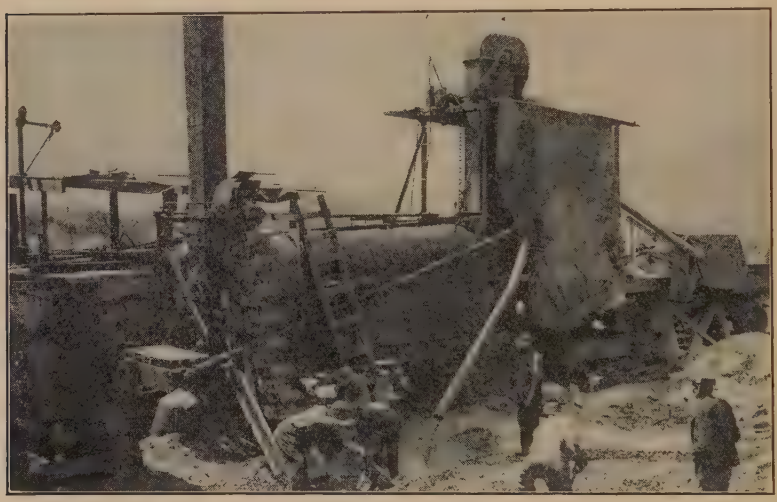


FIG. 86.—A typical asphalt mixing plant.

At best there is a possibility of the Topeka wearing surface creeping and becoming uneven, particularly if the asphaltic concrete itself is not of the proper composition. This difficulty is encountered less frequently with the Warrenite-Bitulithic type of surface than with the other types, and less frequently with a macadam base than with the concrete base. It is probably safe to say, however, that on any city street except one in a residence district with light traffic the asphaltic concrete should be placed on a concrete foundation.

Thickness of Surface.—The thickness of the surface after rolling is rarely less than 2 in., even on light-traffic streets or roads, and that thickness is used almost universally on all classes of streets and roads. It seems to be impractical to use a lesser

thickness without it being displaced by traffic and a greater thickness is apparently unnecessary except for very heavy-traffic streets.

A few pavements have been constructed where the thickness of the surface has been made 3 in., but these are infrequent.

The surface layer is ordinarily placed directly on the foundation without any intermediate or binder course such as is used in the sheet asphalt pavement. Undoubtedly the Topeka type of aphaltic concrete would be more stable if placed on a binder course.

Mixing and Placing.—The mixing is accomplished in a plant identical with that used for sheet asphalt. The mineral aggregate and the bitumen are heated separately and combined by weighing accurately the proportion of each size of stone, sand, filler, and bitumen, and then mixing in the twin-pug or some similar mixing. For the Topeka type of asphaltic concrete the mineral aggregate is separated into two sizes in the storage bins, while for the other types four or more sizes are recommended. The proper quantity of each size is weighed into the mixer, the dust and asphalt cement added and the whole thoroughly mixed.

The mixing is accomplished at temperatures ranging from 250 to 350°F., the variation being necessary on account of the difference in the asphalt cement.

Laying the Surface.—The paving mixture is hauled in trucks from the plant to the place where it is to be laid and at the place of delivery the mixture is dumped on the foundation somewhat ahead of where it is to be spread. It is then shoveled to place and spread by means of rakes, care being taken to loosen the entire mass in so doing. As with sheet asphalt, mechanical spreaders are coming into use and are operated just as those employed for sheet asphalt. When spread, the mixture is rolled with a heavy tandem or macadam roller operated both longitudinally and crosswise of the street. On narrow pavements or country roads the transverse rolling is impractical and all rolling is done longitudinally and diagonally. Careful and thorough rolling is a very essential part of the construction because it affects not only the durability but the evenness of the pavement. The tandem type of roller weighing 8 or 10 tons is commonly used for the Topeka type of asphaltic concrete, while the macadam type of roller weighing about 10 tons is recommended for the coarse-aggregate types of asphaltic concrete.

Dressing the Surface.—Several methods of finishing the surface are employed.

After the first rolling, a light dressing of portland cement may be spread on the surface, and subsequent rolling will incorporate the cement with the surface.

A *seal coat* of the asphalt cement may be spread with the mechanical or hand squeegee and covered with pea gravel and then rolled just enough to set the gravel into the seal coat. The surface is sometimes covered with pea gravel or stone chips and the seal coat omitted. Probably the seal coat with stone chips, or pea gravel, forms the best surface.

Suburban Roads.—Asphaltic concrete of all kinds, except Topeka, is widely used for resurfacing suburban and state roads of macadam or gravel and for new construction on a concrete foundation. These roads are comparatively narrow, being seldom over 20 ft. wide and often being of less width. Vehicles are sure to cross and recross the edge of the wearing surface and if no marginal curb is employed, the edge of the wearing surface will gradually break down and start the disintegration of the surface. The marginal curb of concrete or a substantial shoulder of macadam is necessary for such roads, but otherwise they are constructed in the same manner as city streets of like material.

Characteristics.—The asphaltic concrete is resilient, dustless, quiet and easily cleaned. It is only slightly slippery, being less so than the sheet asphalt. Its durability depends upon many factors, but in general, is about the same as sheet asphalt.

Maintenance.—Assuming that the pavement has been well built, the first need will be a renewal of the seal coat and dressing. If a heavy asphaltic oil is used for this purpose, it will renew the surface and restore the elasticity of the asphalt cement near the surface and thus give the pavement a new lease of life. Breaks in the surface are patched by cutting out the old material to a neat, rectangular opening with vertical faces and refilling with new materials of the same composition as the old pavement.

Tools and Appliances Used for Sheet-asphalt and Asphaltic-concrete Construction

Mixing Plants.—Mixing plants are of many types and designs and vary in size from those that can be loaded on a single flat car and have a capacity of 1,000 sq. yd. a day to those that are permanently located in the larger cities and have a capacity

up to 10,000 sq. yd. a day. Regardless of the size of plant, essential parts are the same, the difference being only in details and size.

Sand and Stone Heaters.—The same heaters are used both for sand and stone and they consist of metal cylinders mounted so they will revolve over the furnaces. The cylinders are mounted at a slight inclination and structural angles are riveted lengthwise to the inside of the shell with one leg projecting. As the cylinder revolves, the material is carried up on these projecting angles until it finally drops. But since the cylinder is inclined, the material will fall ahead of where it started and thus gradually move through the cylinder while being heated. A fan is provided to force heated air through the cylinder, and to remove any dust that may be in the sand.

Screens.—The mineral aggregate is introduced into the heater in about the proportions that experience and tests show is desired, but after being heated, the material is elevated to a revolving screen where it is separated into two or more sizes and deposited in the storage bins. The number of bins and the sizes into which the material is separated depends upon the character of the pavement and the degree of refinement desired in the mixture. For sheet-asphalt wearing surfaces the screen is used to reject the oversize sand. For asphaltic concrete of the Topeka type two sizes are commonly used; namely, stone passing a ½-in. screen and retained on a 10-mesh screen, and sand passing the 10-mesh screen.

For asphaltic concrete of the Warrenite-Bitulithic type a larger number of sizes is desirable for satisfactory grading, and the following are recommended: The minimum screen opening to be $\frac{1}{10}$ in., and the maximum not greater than $1\frac{1}{2}$ in. The difference in the width of openings of the portion of the screen having openings less than ½ in. in size being not to exceed ¼ in., and in the sections having openings larger than ½ in. the difference in size between successive sections being not to exceed ½ in. The following sizes of opening prove satisfactory: $\frac{1}{10}$ in., ¼ in., ¾ in., 1 in., and $1\frac{1}{2}$ in.

Storage Bins.—The hot sand and stone will retain heat for some hours and to prevent delays and to facilitate the work, storage bins are provided for the hot aggregates. These storage bins are below the screen, the several compartments of the bins corresponding to the several sizes of the screen. The problem

that presents itself in connection with the storage of aggregates is how to prevent segregation of sizes either when the material is deposited in the bins or when it is drawn off from them. If the materials fall directly into the bin from the screens, the fine material will fall on one side and the coarse on the other. A hopper should be provided into which they will fall and flow to a central spout and thence to the bin. The bin should be conical, at least have a conical bottom, and should be kept fairly well filled up during the working period so that the weight will keep the entire mass down to the gate. If the bin gets low and sand is likely to draw down in the middle of the bin, the coarse particles will inevitably run down into the hollow thus formed and be drawn out first. Most troubles of this sort are avoided if the bin is worked at least half full.

Asphalt Cement Melting Tank.—The melting tanks are heated with steam coils in all modern plants, but oil, coal, and wood furnaces are also used to some extent. The tank is rectangular-shaped with a cylindrical bottom, the capacity varying from 2 to 50 tons. Regardless of the method of heating used, perforated steam or air pipes are placed in the tank so that a jet of steam or air may be blown through the asphalt cement to stir it.

Mixers.—For sheet asphalt and asphaltic concrete the twin-pug type of mixer is used, the only difference between the machines for the two kinds of mixture being that the one used for asphaltic concrete has fewer and shorter paddles than are used for the surface mixture. Badly worn blades on the mixer shaft are often responsible for poor mixing; therefore, the blades should be inspected regularly and replaced as they wear. The mixer is often steam-jacketed so that it can be kept hot during the mixing. It is placed on a platform which is high enough to allow the trucks to drive underneath. The batch is dropped into the truck through a door in the bottom of the mixer.

Proportioning.—The basis of the proportioning is the "box" of 9 cu. ft. weighing about 1,000 lb., which is the amount commonly mixed at one batch. The mixture is set for the proper weight of each kind of material for this quantity, and all proportions are determined by actual weighing. The Warrenite-Bitulithic plants are equipped with a multibeam scale for convenience in weighing the several portions that make up the mixture.

Rakes.—A special type of stout rake with straight lines is used for spreading the mixtures on the street.

Mechanical finishing machines are being developed for use on asphalt pavements. The sheet-asphalt surface can be finished with a machine similar to that which is used for portland-cement concrete.[1] Slightly modified, it is also used for asphaltic concrete. A machine with a rotating rake has been developed for finishing surfaces of this type. The rake is followed by a screed that insures a surface of the desired thickness.

A machine for rolling and tamping by means of compressed-air hammers has also been devised and operated with some degree of success.[2]

Smoothing Irons, Tampers.—These are of special design with metal handles so that they can be used hot.

Rollers.—The 2- to 4-ton tandem roller is used for the initial compression and the 8- or 10-ton tandem roller for the final rolling, except that the three-wheeled or macadam type weighing about 10 tons is generally recommended for the asphaltic-concrete pavements and heavy-traffic type sheet pavements.

Asphalt Trucks.—The trucks used for hauling the surface mixture may be metal dump-body type but the 2-ton capacity is most common as it is desired to maintain fairly good speed in delivering the hot material.

Problems

1. A water-bound macadam surface is found to have a width of 20 ft., a crown of 7 in., and a thickness of 8 in. It is to be surfaced with asphaltic concrete. Design the cross-section for the reconstructed pavement.
2. Prepare a table showing the thickness and composition of each layer of the following types of pavements, assuming they were constructed properly for a location where the maximum wheel load is 6,000 lb.: (*a*) asphaltic concrete of the coarse-graded type with a concrete base; (*b*) Topeka asphaltic concrete on a concrete base; (*c*) Warrenite-Bitulithic on black base; (*d*) sheet asphalt on a concrete base.
3. Design the cross-sections for a pavement 40 ft. wide where the maximum wheel load is 10,000 lb. and no parking is permitted. Alternate bids are to be received on sheet asphalt and asphaltic concrete.
4. The mineral aggregates for a batch ("box") of asphaltic concrete weigh 1,120 lb. The mixture is to contain 8 per cent of bitumen and the asphalt cement is fluxed Bermudex which contains 95 per cent bitumen. Compute the amount of asphalt cement per box.
5. Write an open specification for an asphalt cement to be used on a boulevard (automobiles and busses the only vehicles permitted to use the street) in a city in central Indiana.

[1] JAMES, GUY H., "Concrete Finishing Machine Spreads Asphalt Surfacing," *Eng. News-Rec.*, Vol. 100, No. 13, March, 1929, p. 511.

[2] GODSON, H. P., "Traffic-way Pavements," *Canadian Engineer*, Vol. 51, No. 15, Oct. 12, 1926, p. 192.

CHAPTER XX

ECONOMIC COMPARISONS OF ROADWAY SURFACES

In economic comparisons of the various means that may be available or may be made available for conducting highway transportation there must be consideration not only of those costs that accrue on account of the highway but also of those that accrue on account of the vehicle. Actually these are closely related and quite often vary together. The total, or more properly, the true cost of highway transportation is a combination of vehicle costs and highway costs and neither is complete without the other.

It is difficult to ascertain the true cost of highway transportation because the vehicles are under the ownership of millions of individuals, most of whom make no attempt to keep records of the cost of vehicle operation and the roadway is publicly owned and is administered by officials who may or may not keep complete records of cost (usually they do not).

The mutual adaptation of road and vehicle to the end that transportation costs will be a minimum is almost wholly impossible under these conditions. To begin with, authoritative data on costs is lacking and officials cannot therefore determine with certainty what policy to adopt, and even if they did formulate a policy, the administrative problem of securing harmonious and concerted action by the builders of highways and the manufacturers of vehicles is a tremendous one. The matter is still further complicated by the fact that both groups (public officials and vehicle manufacturers) must in the last analysis depend upon public support to make their actions effective. The public can not sense that there are broad economic problems involved in the development of a highway system and can but dimly comprehend the basic principles when they are expounded.

The public cannot by any stretch of imagination be conceived to have more than a remote conception of the economic loss that results from improper highway design or construction. This loss is unquestionably enormous but it is made up of millions

of small items that are concealed in those every day expenses of vehicle operation or road maintenance that are taken as a matter of course. The only barrier to the indefinite continuation of this economic waste is the predilection of the engineer to improve his work constantly out of sheer love of doing things as nearly correctly as his working relations will permit.

The following discussion of the economic principles involved in providing highway transportation at the minimum cost must therefore concern itself with both vehicle costs and highway costs.

I. HIGHWAY COSTS

The development of highway systems in the United States has reached the stage where some clearly defined method of ascertaining the influence of the various types of roadway surfaces upon transportation costs is needed to assist officials in solving properly a number of questions of administration and finance. It would be particularly helpful in connection with the selection of types of surfacing and the establishment of fair rates of tax imposts on vehicles, where that method is adopted for securing funds for the construction and maintenance of highways.

It is becoming the policy of many highway departments to proceed on the theory that a considerable part of the cost of the construction and maintenance of highways should be borne by the vehicles that use them. It often happens that types of roadways are constructed, or old roads continued in service, that require maintenance expenditures in excess of the service value of the roadway surface and therefore place an undue burden on the maintenance funds.

In the past it has been the custom to assume that in general a road surface was worth its first cost, and that the relative values of various classes of highway surfaces were correctly indicated by their relative prices. Now it is beginning to be recognized that price is merely one factor to be considered in comparing types of surfaces, and that the actual value of the surface is dependent upon factors only indirectly related to first cost or contract price.

Value of a Highway.—Value is defined in various ways in dictionaries, and, with reference to its use in the science of valuation, by authors and authorities on valuation. Nearly all of the definitions that appear in treatises on the science of

valuation carry the idea that value is related to income-producing ability and, since highways do not produce income in the commercial sense, it is necessary to arrive at a somewhat different conception of value as applied to public highways. This may be accomplished by considering that highways are intrinsically valuable because they are an essential element of a service people desire and are willing to pay for. The value of a specific roadway surface depends upon its effect on the cost of transportation. The determination of appropriate improvements for a specific highway and the selection of types of surfaces becomes a problem of evaluating the effect of those improvements on the cost of highway transport.

There is not at present sufficient available information to permit accurate highway transportation costs to be established but there are fragmentary data that permit of comparisons that are considerably better than outright guesses. When more attention is given to the analysis of highway transportation costs, there will be more systematic cost keeping and the basic data needed will gradually become available.

Basis of Value.—Since the highway transportation plant may not be operated for direct profit, its value cannot be based upon ability to produce income but may be expressed in terms of the quantity of transportation service produced per unit of expenditure. Obviously the cost of transport will depend in part on the type of vehicular equipment, but by considering the equipment existing in any locality, comparative values for various types of highways in that location may be estimated.

Unit of Measure.—If it be admitted that the value of a highway is measured by the quantity of service it renders per unit of expenditure there remains the need for adopting some measure of this service that will take into account variations in width of highway and density of traffic. British engineers express this quantity in terms of *annual cost per square yard, per ton of traffic per yard of width,* but it appears that a more convenient unit for use in the United States would be *annual cost per mile of surface 1 ft. wide, per ton of traffic per foot of width,* or more concisely, *annual cost per unit of road, per unit of traffic.*

Life Tonnage.—A unit of this character presupposes that there is a reasonably definite life tonnage for each type of construction. In any one locality the traffic is reasonably stable in character and it is probably true that for any specific type of construction there

is a reasonably definite life tonnage, but since deterioration of a road surface is in part due to the elements and in part due to kind as well as quantity of traffic, that type might not have an identical life tonnage in all localities. It is also probably true that the life tonnage will depend somewhat upon the annual tonnage, since deterioration is in part a function of time. Certain types of roadway surface deteriorate more rapidly if there is no traffic than if there is a reasonable amount of traffic and with nearly all types of pavement surfaces the cost of maintenance per unit of traffic decreases with an increase in traffic, at least up to a certain critical traffic density.

Economic Theory of Costs.—Without entering into a discussion of the various methods that have been suggested for computing the annual cost of furnishing highway service, this presentation will be based on the theory outlined by Messrs. Gillette and Dana in "Mechanical and Electrical Cost Data" which is not only fundamentally sound, but also easily applied to the problems of the highway engineer.

Roadway Surface Costs.—The annual cost of the roadway surface during its economic life may be computed as follows:

$$C = M + (I - S)f + IR \tag{40}$$

in which

C = the annual cost per unit of roadway surface.

M = the equated annual cost of maintenance per unit of roadway surface.

I = the initial cost per unit of roadway surface, including administrative and engineering overhead.

S = the salvage value per unit of roadway surface at the end of its economic life.

f = the annual deposit that will accumulate \$1 in a period equal to the economic life of the roadway surface, with interest at 4 per cent compounded annually.

R = the rate of interest applicable to highway costs taken herein at 4 per cent.

Having determined the annual cost per mile of surface 1 ft. wide, the cost per ton-mile of traffic may be determined by dividing that cost by the average annual tonnage of traffic per foot of width of surface. It will be apparent that before calcu-

lations can be made in accordance with Formula (40), the proper values must be secured for the several terms.

Initial Cost.—In applying the method to a specific highway it will usually be possible to determine the contract price of the roadway surface. To this must be added the cost of administration and engineering to obtain the factor I. Administration and engineering costs vary from 3 per cent. in the case of well handled state highway work to as much as 10 per cent. in some municipal work. Where the exact data are lacking, 5 per cent. may be used as representing a fair average.

Fig. 87.—Illustrating computation of annual cost and economic life.

Maintenance Cost.—The cost of maintenance is often difficult to determine, since the records available are not always complete and do not cover a long enough period to make possible the establishment of a maintenance cost curve for the entire economic life period. Curve 1 in Fig. 87, showing the average total cost of maintenance at the end of each year of age of a certain group of pavements in Buffalo, N. Y.[1] is typical of the kind of information needed. If this curve is other than a straight line, it is necessary to take account of the time value of money in determining the average annual cost of maintenance during the economic life of the surface. That is accomplished as follows: Compute the sum

[1] 24th *Report*, Bureau of Engineering, Buffalo, N. Y.

to which the maintenance cost for each year would amount if placed at compound interest until the end of the economic life of the roadway surface. Add together all of these sums and then determine the annuity required to produce that quantity during the economic life of the roadway surface. This theoretical annual deposit is the factor M in Formula (40). If the curve of annual maintenance cost is a straight line, obviously the costs equate themselves and the arithmetical average cost may be used for the factor M in Formula (40).

Salvage Value.—The salvage value of the roadway surface may be considerable or it may be zero, depending upon the type of construction and the type that is to be used to replace it. The concrete base of a sheet or block pavement can be utilized for some new type or the thickness of a new pavement may be affected by the existence of an old macadam or gravel roadway. In general, salvage value is the difference between the cost of a new roadway surface when constructed over some existing surface and the cost of the same type of new roadway surface when constructed in the same locality without utilization of an existing surface. Obviously the design for the new construction must contemplate the utilization of the old roadway or its full salvage value will not be realized.

Traffic.—The average annual traffic to which a roadway has been subjected is difficult to determine because in the United States there has been little attempt to keep systematic records of traffic. British engineers have done rather better in this respect. In the absence of exact information in regard to the tonnage that necessitated the maintenance expenditure, comparisons of types may often be made on the basis of estimated *relative* volumes of traffic, but such estimates are of little value unless prepared by an engineer of long experience who is well acquainted with the territory in which the highways are located.

Economic Life.—The economic life of a roadway surface has been reached when the annual cost reaches a minimum. It is conceivable that by careful maintenance a roadway surface might be continued in service after it had reached its economic life but the cost of maintenance would be such that it would prove economical to replace the roadway surface instead of endeavoring to prolong its life. In this connection it must be understood that the maintenance is handled so as to keep the roadway surface at its maximum of serviceability. If traffic is compelled

to use inadequately maintained surfaces, vehicle operating costs are adversely affected and the burden of expense is transferred to the vehicle owner.

At the end of its economic life, the roadway surface has deteriorated to its salvage value and no further depreciation need be considered. The annual cost of the service rendered beyond the economic life period is therefore computed as follows:

$$C_1 = M_1 + RS \tag{41}$$

where

C_1 = the annual cost per unit of surface during any period beyond the economic life of the surface.

M_1 = the equated annual maintenance costs during the period.

R and S have the same significance as before.

There is no depreciation term in Formula (41) because by the very assumption upon which the formula is based, the surface has already reached its economic life and therefore its maximum depreciation.

Computing Economic Life.—Formulas (40) and (41) afford a means of actually computing the economic life of a roadway surface, for by means of Formula (40), the cost of service from a new surface can be estimated and by means of Formula (41) the cost of service from an existing surface can be computed and whenever C_1 becomes greater than C, the economic life of the surface has been exceeded.

This will perhaps be clearer from the following illustration. Since the character of the traffic will be the same on a new as on the old surface (if the old is properly maintained), traffic tonnage may be disregarded in computing economic life.

Assume the cost of maintenance to follow curve 1 in Fig. 87. The cost of a new roadway surface to replace the existing one is \$1.55 per square yard and its salvage value will be zero. The initial cost of the existing surface was \$3.30 per square yard and its salvage value is \$1.75 per square yard. Interest to be at the rate of 4 per cent and in all calculations to be compounded annually.

Calculate the value of C on the assumption that the economic life of the existing surface is 20 years. Then recalculate on the assumption that the economic life is 25 years, and again on the assumption that it is 30 years. In this way enough points can be obtained to determine curve 3, Fig. 87.

If the assumption that the economic life was 20 years were correct, Formula (41) could be used for determining the cost for the twenty-first year. Likewise if the assumption that the economic life is 25 years were correct, Formula (41) could be used for computing the cost for the twenty-sixth year. In this way enough points could be computed to determine curve 4, Fig. 87.

The intersection of curves 3 and 4 determines the economic life of this particular pavement to be 27½ years. At the age of 27½ years the annual cost per unit of pavement is very nearly $110. The life tonnage is unknown for this particular case but by comparing with other pavements in similar locations it is estimated to be 6,000 tons per foot of width, per annum and the total annual roadway surface cost is therefore very nearly 2 cts. per mile 1 ft. wide per ton of traffic.

Application to Highway Systems.—A state highway system is constructed section by section, over a long period of years. If each section is well cared for and is replaced when it reaches its economic life, the average annual expenditure for the maintenance of each type of roadway surface comprising the system will be very nearly the same as the theoretical equated annual cost of maintenance. In computing the actual annual cost of a system of highways it is perhaps sufficiently accurate to use the recorded average annual maintenance costs for each type since certain other factors must be estimated in any case.

In any administrative area the economic life for each type of roadway surface should be determined in enough instances to establish the average economic life for various traffic densities, and, similarly, the maintenance cost, salvage value and other factors should be evaluated by analysis of the data pertaining to a large group of roadway surfaces of each type.

It has been impossible to do that with certainty heretofore because of lack of published data but from a study of all of the records available there has been prepared a table of tentative average values for these various quantities which are given in Table XXII. In any state or city the records would doubtless show where the factors presented herein could be revised, but those in the table will illustrate the method of attack, and incidentally illustrate how helpless the engineer becomes if he cannot secure suitable fundamental data for his computations.

TABLE XXII.—ELEMENTS OF ROAD COSTS IN DOLLARS PER MILE ON THE BASIS OF A TWO-LANE (20 FT.) WEARING SURFACE

T = Average Daily Traffic in Tons

Item of cost	Type of wearing surface		
	Low	Intermediate bituminous	High bituminous
1. Right of way	$1,800	$1,800	$1,800
2. Earthwork	$1,500	$2,000	$3,000
3. Annual maintenance of right-of-way and shoulders	$25	$35	$50
4. Annual maintenance of road surface	$150 + \frac{T}{1.5}$	$250 + \frac{T}{2.5}$	$100 + \frac{T}{8}$
5. Cost of surface	$1,000	$3,500	$30,000
6. Salvage value	.....	.....	$18,000
7. Economic life	.....	.....	20 yr.

Relation of Maintenance Costs to Volume of Traffic.—It is recognized that there is a relation between the cost of maintenance of a roadway surface and the quantity of traffic, but there have been few attempts to measure the effect of increasing traffic on maintenance costs. In some cases the increased cost has been attributed to the increased age of the roadway surface when in reality it is due to increased traffic. From an analysis of such records as have come to hand it appears that the variation in cost of maintenance with a change in traffic may be estimated from the following formula:

$$\text{Average Annual Maintenance Cost} = K + \frac{\text{Average Annual Traffic in Tons}}{P}$$

The factors K and P are wholly arbitrary and their values will vary in the states according to climatic and traffic conditions. For states in the upper Mississippi Valley they appear to have the following values:

	K	P
Low-type surfaces	150	550
Intermediate-type surfaces	250	900
High-type surfaces	100	3000

Additional Items of Cost.—The roadway surface has been discussed in the foregoing analysis but the true cost of providing

a highway must include some additional items and the annual cost of each of these may be computed from Formula (20) by inserting appropriate values for the various items.

Maintenance Right-of-way.—The items of maintenance of right-of-way is the cost of cutting weeds, cleaning out ditches, preventing or repairing damage from erosion, and similar upkeep. Since these costs do not vary greatly from year to year they equate themselves and the average cost may be used instead of the equated cost of maintenance used for roadway surfaces. This item varies greatly according to soil and climatic conditions but ranges from $25 to $50 per mile per year for trunk-line highways.

There has been much discussion of the proper interpretation of the term $(I - S)f$, as applied to right-of-way. In the case of old established roads the original right-of-way was taken from the adjacent lands and will revert to them if abandoned, or in effect, I and S are equal and term $(I - S)f$ vanishes. If the right-of-way was actually purchased in any case it is exceedingly difficult to predict its salvage value, but it is safe to say that in the vast majority of cases it would equal the initial cost and it might exceed it. The cases of abandonment are so few, however, that no consideration need be given to that possibility. When the right-of-way continues in use for a long period of time f becomes so small that it does not affect the annual cost for right-of-way. No serious misconception will result in the usual case by considering the term $(I - S)f$ equal to zero.

The term IR remains and herein lies another possible source of error. Even if the right-of-way were donated or simply taken from adjacent lands it should be considered to have value and that value is that which the land possesses now, whatever may have been the price when the land was dedicated to highway purposes.

From the foregoing it will be apparent that the element of transportation cost arising on account of right-of-way really reduces to the two terms maintenance and interest.

By following a similar analysis, the transportation cost arising out of the construction of bridges, culverts, guide signs, and various incidentals may be computed. These annual costs added to that of the roadway surface afford a correct measure of the portion of highway transportation cost that accrues from the construction and maintenance of the highway.

Total Highway Costs.—Following the methods outlined in the preceding discussion and using the data in Table XXII as a basis, there have been prepared estimates of the actual total annual costs of two-lane highways with various classes of roadway surface and having traffic densities up to 6,000 tons per day, exclusive of the exceedingly variable item of bridges and culverts. These are shown in Fig. 88 and it will later appear that considerable error may exist in these costs without materially changing

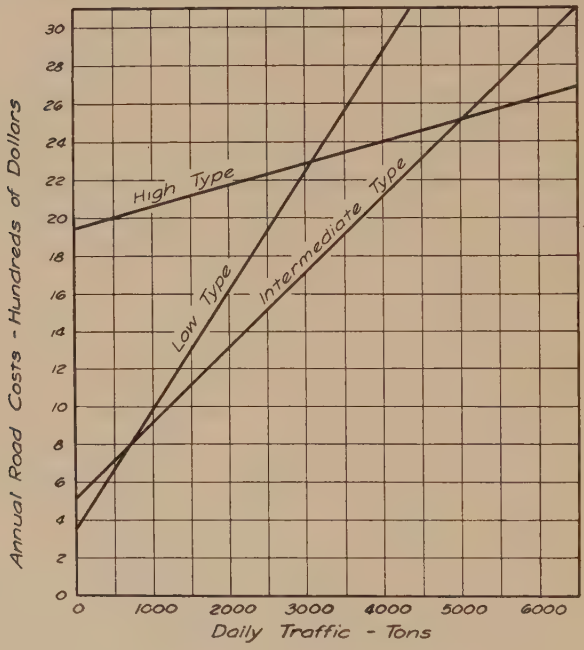


FIG. 88.—Relative cost of groups of roads as related to traffic.

the relative total cost of transportation on the various types of roadway surface.

Relation between Type of Highway and Vehicle Costs.—It is generally recognized that there is a relation between the type and condition of the roadway surface and the cost of such items as fuel, oil, tires, repairs, maintenance, and depreciation. Tentative estimates of this relationship have appeared from time to time, but traffic is changing in character so rapidly that exact analysis has been impossible as yet.

TABLE XXIII.—AVERAGE COST OF AUTOMOBILE OPERATION

Based on detailed cost records covering about 800 automobiles operated in various parts of the United States and an average of 11,000 miles per year. The reports were largely from fleet operators who purchase supplies at wholesale and the items of gasoline and tires have been converted to retail price basis.

Type of car	Light 4[2] average		Medium 4[3] average		Heavy 4[4] average		Light 6[5] average		Medium 6[6] average		Heavy 6[7] average	
Gross weight, tons (approximate)	0.86		1.08		1.4		1.41		1.66		1.86	
Items[1]	Dollars per year	Cents per mile	Dollars per year	Cents per mile	Dollars per year	Cents per mile	Dollars per year	Cents per mile	Dollars per year	Cents per mile	Dollars per year	Cents per mile
1. Gasoline at 20 cts. per gallon	147.40	1.34	125.40	1.14	144.10	1.31	149.60	1.36	167.20	1.52	157.30	1.42
2. Oil	27.50	0.25	18.70	0.17	17.60	0.16	19.80	0.18	22.00	0.20	18.70	0.17
3. Tires and tubes	66.00	0.60	71.50	0.65	77.00	0.70	82.50	0.75	88.00	0.80	99.00	0.90
4. Maintenance	170.50	1.55	210.10	1.90	227.70	2.06	214.50	1.95	236.50	2.14	278.30	2.53
5. Depreciation	137.50	1.25	154.00	1.40	172.70	1.57	192.50	1.74	229.90	2.09	282.70	2.57
6. License	12.00	0.11	15.00	0.14	22.00	0.20	22.00	0.20	26.00	0.24	30.00	0.27
7. Garage at $4 per month	48.00	0.44	48.00	0.44	48.00	0.44	48.00	0.44	48.00	0.44	48.00	0.44
8. Interest at 6 per cent	30.00	0.27	42.00	0.38	60.00	0.55	60.00	0.55	78.00	0.71	95.70	0.87
9. Insurance (fire, theft, tornado, liability)	23.00	0.21	22.00	0.20	23.00	0.21	23.00	0.21	28.00	0.26	30.00	0.28
Total	661.90	6.02	706.70	6.42	792.10	7.20	811.90	7.38	923.60	8.40	1,039.70	9.45
Annual mileage	11,000		11,000		11,000		11,000		11,000		11,000	
Average miles per gallon gas	14.95		17.53		15.29		14.68		13.19		14.02	

[1] 1. From reported costs reduced to uniform price per gallon.
2. Average reported.
3. Based on average retail prices of tires.
4 and 5. Reported for vehicles that had been operated for a period and then sold.
6. At the Iowa rate, *i.e.*, 40 cts. per hundred-weight plus 1 per cent of list price.

[2] Light 4—Ford, all types.

[3] Medium 4's—Chevrolet, Star, Overland.

[4] Heavy 4's—Dodge, Nash, Maxwell, Chrysler, Oldsmobile, Hupmobile.

[5] Light 6's—Essex, Chrysler, Oldsmobile, Studebaker, Oakland.

[6] Medium 6's—Chrysler, Buick, Jewett, Studebaker, Nash, Chandler.

[7] Heavy 6's—Buick, Studebaker, Hudson, Paige, Reo.

The costs of operation for several classes of automobiles are given in Table XXIII.[1]

It is believed that the effect of road condition upon vehicle operation costs may be estimated within reasonable limits by the correct interpretation of a mass of research data that has appeared in recent years, the more important of which are presented in the publications listed in the bibliography at the end of this chapter. The relative cost estimates presented later were accordingly prepared in that way and the several assumptions in the analysis are as follows:

1. In order that seasonal variation in road condition may be taken into account, it was assumed that an automobile is operated regularly throughout the year, traveling at a speed of 30 to 40 miles an hour, and that the schedule (but not the speed) is maintained regardless of the condition of the roads, so long as operation is possible. That is, the vehicle makes regular daily or weekly trips or some other fairly regular trip schedule and does not avoid the days when the roads are not at their best.

2. The relative rate of tire wear is assumed to be 1.00 for high type roads, 2.12 for intermediate types and 2.90 for low types.

3. The maintenance cost of the vehicle is assumed to vary in accordance with the work done by the motor in various kinds of service, measured by the rate at which the motor delivers power and uses fuel. This presupposes that the maintenance of the vehicle is due entirely to the wearing of parts, which is a conservative view to take, since other factors add to the effect of mechanical deterioration, especially when the vehicle is operated on low-type roads.

4. Depreciation in the value of the used vehicle is due in part to mechanical deterioration and in part to obsolescence. It is assumed that one-half of the depreciation is chargeable to mechanical deterioration and one-half to obsolescence. The portion that is due to mechanical deterioration is assumed to vary with the work done by the motor as measured by fuel consumption. This view neglects the effect of road condition on the deterioration of the body of the vehicle.

5. From all of the accessible record of tractive resistance of automobiles, the average tractive resistance for year-round operation at a speed of about 35 miles an hour was estimated for the three classes of roads as follows:

High types (pavements of all kinds in average good condition)	70 lb. per ton
Intermediate types (gravel, macadam, and bituminous-treated surfaces)	110 lb. per ton
Low types (natural soil roads and light gravel or sand-clay surfaces)	160 lb. per ton

[1] AGG, T. R., and H. S. CARTER, "Operating Cost Statistics of Automobiles and Trucks," *Bull.* 91, Iowa Engr. Exp. Sta., Ames, Iowa, 1928.

6. With these values of tractive resistance the average relative gasoline consumption was determined from reported engine tests and actual measurements on the road. The following results were obtained:

High types	1.00 of basic rate
Intermediate types	1.20 of basic rate
Low types	1.47 of basic rate

The above figures signify that, as the average throughout the year, if a vehicle will travel 15 miles on a high-type road per gallon of gasoline, it will take 1.2 gal. of gasoline to travel 15 miles on an intermediate type, and 1.47 gal. to travel 15 miles on a low type. Of course there are times when there is little or no difference in the mileage per gallon on the several types of roads, but a comparison of the nature desired must be based on year-round conditions.

The effect of these several variables upon cost of operation is most readily presented in the form given in Table XXIV in which factors are used to indicate the relative cost of each item of operation on three general classes of road. If the cost of any item is known for one type of road, the cost for either of the other types may be calculated by the use of the appropriate factor from Table XXIV. Obviously some items of operating cost are not directly influenced by road conditions. For convenience, the high type is used as the basis of comparison.

TABLE XXIV.—EFFECT OF ROAD CONDITION ON VARIOUS ITEMS OF OPERATING COST

Item of cost	Sum expended for the item when using high-type roads	Sum required for equal mileage on intermediate-type roads	Sum required for equal mileage on low type roads
Gasoline	$1	$1.20	$1.47
Oil	1	1.00	1.00
Tires and tubes	1	2.22	2.90
Maintenance	1	1.20	1.47
Depreciation	1	1.10	1.24
License	1	1.00	1.00
Garage	1	1.00	1.00
Interest	1	1.00	1.00
Insurance	1	1.00	1.00

In attempting to present a figure representing the "average cost of automobile operation," one is confronted with the fact that no specific automobile is an "average" automobile, although some classes are near the average in cost of operation. What is desired is the figure obtained by dividing the total cost of operating all cars during some period, say one year, by the total mileage operated for the period. No such figure is available but from reports on automobile operating costs a table has been prepared to show the cost of operation for an imaginary "average" automobile,[1] which is Table XXV.

TABLE XXV.—COST OF OPERATION OF AN IMAGINARY "AVERAGE" AUTOMOBILE

(Annual mileage of 11,000)

ITEM OF COST	CENTS PER MILE
Gasoline	1.31
Oil	0.22
Tires and tubes	0.64
Maintenance	1.72
Depreciation	1.39
License	0.14
Garage at $4 per month	0.44
Interest at 6 per cent	0.36
Insurance (fire, theft, tornado)	0.21
Total cents per mile	6.43

Since the automobiles upon which the cost reports tabulated herein were received, were operated on all sorts of roads, the general average given in Table XXV probably represents the cost of operation on intermediate-type roads more nearly than it does the cost on either high-type or low-type roads, and it is so considered. Whether this is true or not is relatively unimportant in the analysis that follows, as will be apparent from a casual examination of the tables. By applying the factors of Table XXV to the cost figures of Table XXIV there is obtained a close approximation to the relative cost of operating an imaginary "average" automobile on the three types of roads. These costs are given in Table XXVI.

[1] *Ibid.*

TABLE XXVI.—RELATIVE COST OF OPERATING AN IMAGINARY "AVERAGE" AUTOMOBILE ON VARIOUS CLASSES OF ROADS

Item of cost	Approximate relative cost of operation in cents per mile		
	High-type roads	Intermediate-type roads	Low-type roads
Gasoline	1.09	1.31	1.61
Oil	0.22	0.22	0.22
Tires and tubes	0.29	0.64	0.84
Maintenance	1.43	1.72	2.11
Depreciation	1.26	1.39	1.57
License	0.14	0.14	0.14
Garage at $4 per month	0.44	0.44	0.44
Interest at 6 per cent	0.36	0.36	0.36
Insurance	0.21	0.21	0.21
Total cost	5.44	6.43	7.50
Relative cost	1.00	1.18	1.38

Combined Vehicle and Road Costs.—Having determined the vehicle cost per ton-mile for any type of surface and the cost of the highway per ton of traffic, the total cost of highway transport is obtained by adding the two quantities.

TABLE XXVII.—COMBINED VEHICLE AND ROAD COSTS

Type of surface	Traffic density in tons per day									
	50	100	300	500	1,000	1,500	2,000	2,500	3,500	5,000
Low	1,475	2,604	7,117	11,630	22,914	34,197				
Intermediate	1,536	2,495	6,330	10,165	19,573	29,340	38,928			
High	2,745	3,545	6,798	9,950	17,955	25,960	33,965	41,970	57,982	81,970

Note.—Based on a two-lane highway and a weight of 1.25 tons for the average automobile and load.

Since this quantity will vary with the volume and character of the traffic. general tables cannot be prepared, but must be computed for each group of highways of comparable nature. To illustrate the results of such an analysis Table XXVII has been prepared, which is applicable to many highways in the upper Mississippi Valley. Since the relative costs in the table depend primarily upon the accuracy of the data in Table XXVI rather

than that in Fig. 88, care should be exercised to insure that vehicle operating costs applicable to the locality are used.

II. TRAFFIC SURVEYS

In the discussion of highway costs frequent references were made to type and tonnage of traffic on the highways. Reasonably accurate information relative to traffic is fundamental to the correct solution of many problems with which the highway engineer deals and is also needed in connection with various problems of public administration, such as those involved in regulation of traffic, adjustments of rates for commercial highway traffic, and the settlement of disputes arising among carriers.

Two types of survey are being employed for securing information relative to highway traffic, and since their purposes are quite different, it is desirable to distinguish clearly between them. The one is known as the highway transport survey and has for its purpose an analysis of the commercial opportunity for highway transport operations in a region, or the determination of the proper organization and equipment to employ for highway transport. Surveys of this type are not within the scope of this treatise.

The other has for its purpose the determination of the volumes, weight, and kind of traffic on a highway, or a system of highways, and regional or local characteristics of the traffic.

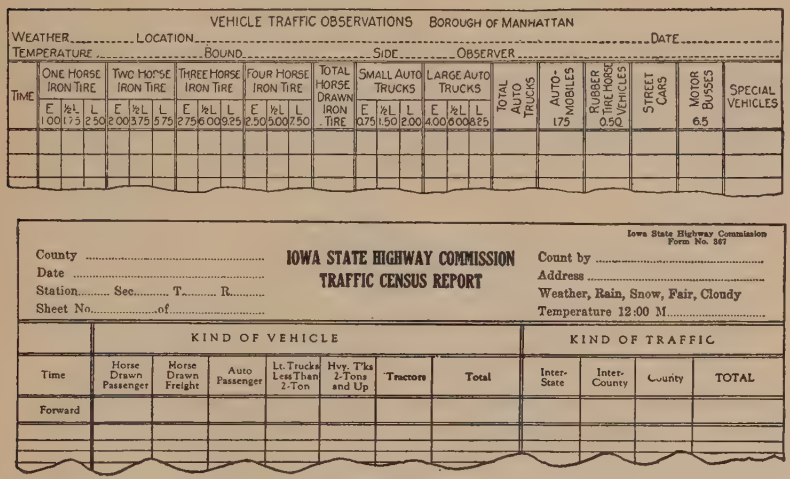
The Traffic Census.—The traffic census is conducted for the purpose of securing the desired information relative to traffic and the nature of the census will vary with the requirements in any specific instance. In many cases the traffic census consists simply of a count of the vehicles for a limited period of time for the purpose of ascertaining the volume of traffic on a highway. The traffic units are generally assigned to arbitrarily established groups and the field party records each vehicle in the proper group. Two forms used for a census of this type are shown in Fig. 89.

Traffic counts of this character can be made by enumerators with little previous experience if they are properly coached and are furnished suitable forms for recording the traffic.

There is as yet no standard procedure for taking the traffic census, but there is sufficient information to enable one to organize a traffic census with assurance that he will secure dependable results.

It seems to be out of the question to count the traffic every day at a large number of stations, because of the expense. Consequently, it has been the custom to take the census for short periods at a comparatively few stations and to attempt to deduce total annual traffic from the results of such enumerations. While it is recognized that this practice is not entirely satisfactory, it is felt that the results so obtained are considerably better than none at all and probably yield a suitable basis for economic comparisons.

Short-period traffic enumerations should be distributed through the year in such a way that there will be a measure of the



VEHICLE TRAFFIC OBSERVATIONS BOROUGH OF MANHATTAN

WEATHER ..... LOCATION ..... DATE .....

TEMPERATURE ..... BOUND ..... SIDE ..... OBSERVER .....

TIME	ONE HORSE IRON TIRE			TWO HORSE IRON TIRE			THREE HORSE IRON TIRE			FOUR HORSE IRON TIRE			TOTAL HORSE DRAWN IRON TIRE	SMALL AUTO TRUCKS			LARGE AUTO TRUCKS			TOTAL AUTO TRUCKS	AUTO-MOBILES	RUBBER TIRE HORSE VEHICLES	STREET CARS	MOTOR BUSSES	SPECIAL VEHICLES
	E	½L	L	E	½L	L	E	½L	L	E	½L	L		E	½L	L	E	½L	L					
	1.00	1.75	2.50	2.00	3.75	5.75	2.75	6.00	9.25	2.50	5.00	7.50		0.75	1.50	2.00	4.00	6.00	8.25		1.75	0.50		6.5	

Iowa State Highway Commission
Form No. 387

County .....
Date .....
Station..... Sec..... T..... R.....
Sheet No..... of .....

IOWA STATE HIGHWAY COMMISSION
TRAFFIC CENSUS REPORT

Count by .....
Address .....
Weather, Rain, Snow, Fair, Cloudy
Temperature 12:00 M.....

	KIND OF VEHICLE							KIND OF TRAFFIC			
Time	Horse Drawn Passenger	Horse Drawn Freight	Auto Passenger	Lt. Trucks Less Than 2-Ton	Hvy. T'ks 2-Tons and Up	Tractors	Total	Inter-State	Inter-County	County	TOTAL
Forward											

FIG. 89.

seasonal and daily variations of traffic and the amount of night traffic. Sunday and holiday traffic counts are valuable as showing the peak loads that may be expected, and should be given the proper weight in computing or estimating the annual total.

Traffic Weighing.—Traffic weighing is resorted to as a means of preventing or controlling overloading of vehicles to the detriment of the road, but that is only a partial traffic survey.

In order to secure accurate information upon which to base a category of vehicle weights and to measure fully the tonnage of traffic on a highway, weighing stations are established along the road and each vehicle is required to pass through the weighing station. The weighing is continued at regular intervals for a

year or more in some cases, and in others is carried on for a few weeks at each station. The data secured at the weighing stations of the Connecticut traffic survey are as follows[1] and it will be noted that considerable information is obtained in addition to that pertaining to the weight and quantity of traffic.

Passenger Cars.—Make; license number; roadster (*R*) or touring car (*T*); number of cylinders; number of passengers; time; start of haul; end of haul; miles.

Motor Trucks.—To economize on the time required to interrogate drivers and weigh trucks two forms are filled in by different men, as follows:

Form 1.—License number and state; make; time; capacity in tons; loaded (*L*) or empty (*E*); estimated time required for trip; name of truck owner; name and address of consignor; name and address of consignee; length of haul in miles; character of load; direction of traffic; regular or irregular trip.

Form 2.—License number and state; make; time; total width of body; weight on front axle; weight on rear axle; tires, solid (*S*), cushion (*C*), dual (*D*), or pneumatic (*P*); width in inches and type of front tire; width in inches and type of rear tire; thickness of time (channel to road surface); condition of tires.

Motorcycles.—License number; single (*A*), or side car (*B*); number of passengers; time; location of start of haul; location of end of haul; miles.

Horse-drawn Vehicles.—Passenger (*P*) or freight (*F*); number of horses; commodity carried; tonnage; time; location of start of haul; location of end of haul; miles.

In all cases record was made of the date and weather conditions.

The composition of the truck traffic[2] on Connecticut highways is shown in Table XXVIII.

The traffic census is, therefore, either an enumeration or an enumeration accompanied by the weighing of traffic, with which is combined the tabulation of various kinds of miscellaneous information.

When a census is taken of the traffic on a city street, it is impossible to include weighing, but the classifications adopted should permit the application of the results of traffic weighing

[1] Report of a Survey of Transportation on the State Highway System of Connecticut," by U. S. Bur. Public Roads and Connecticut State Highway Department, pp. 41–42, 1926.

[2] *Ibid.*, p. 51.

TABLE XXVIII.—WEIGHTS OF HIGHWAY TRAFFIC UNITS

A. Connecticut Trucks

Capacity in tons	Per cent of total number	Capacity in tons	Per cent of total number
½	25.1	3	1.7
¾	3.8	3½	6.7
1	18.4	4	0.7
1¼	12.5	5	10.2
1½	6.0	5½	0.4
2	9.7	6	0.3
2½	3.7	6½	0.6
		7½	0.2

B. Average Automobile

The average weight of automobile traffic per unit, assuming two passengers, is 1.25 tons.

C. English Road Board Categories

	TONS
1. Heavy vehicle, one horse	1.25
2. Light vehicle, one horse	0.40
3. Heavy vehicle, two horses (or more)	2.50
4. Light vehicle, two horse	0.60
5. Horse lead or driven	0.50
6. Motorcycles	0.13
7. Omnibuses, two or more horses	3.00
8. Motor cars	1.60
9. Motor van, covered	2.50
10. Horses, drawing vehicles	0.50

D. Averages, Borough of Manhattan, New York City

TYPE OF VEHICLE	WEIGHT IN TONS
One-horse, iron tire, empty	1.00
One-horse, iron tire, ½ load	1.75
One-horse, iron tire, full load	2.50
Two-horse, iron tire, empty	2.00
Two-horse, iron tire, ½ load	3.75
Two-horse, iron tire, full load	5.75
Three-horse, iron tire, empty	2.75
Three-horse, iron tire, ½ load	6.00
Three-horse, iron tire, full load	9.25
Small automobile trucks, empty	0.75
Small automobile trucks, ½ load	1.50
Small automobile trucks, full load	2.00
Large automobile trucks, empty	4.00
Large automobile trucks, ½ load	6.00
Large automobile trucks, full load	8.25
Automobiles	1.75
Motor Busses	6.50
Horse-drawn vehicles with rubber tires	0.50

elsewhere so that estimates of the tonnage of traffic may be established. This information is very necessary to those responsible for the administration of street improvements, especially in determining the relative costs of types of improvement and the traffic requirements in various areas.

The nature of the traffic census, its duration, and the form in which it is reported, all depend upon the purpose for which it is taken. It is not an end in itself but is one method of securing information to be used in the various analyses that should accompany good engineering work on street or highway improvements.

Analysis of the Traffic Census.—It should be recognized that the traffic census can be no more than a record of the traffic at the time the census was taken. It cannot of itself be a forecast of future traffic nor a measure of past traffic. But even with its limitations the traffic census is the basis of all computations in which traffic is concerned and is the starting point in all analyses of the probable trend of traffic on a specific highway or in an administrative area. Whether it is as yet possible to predict the future traffic when the present traffic is known, is beside the question. If traffic records are kept year by year, the trend will eventually become apparent. Observers seem to think that the present rapid increase of traffic is abnormal and will not continue for more than a few years. Once the saturation point is reached, the trend will in general follow some law of slow growth.

Traffic records should be taken to complete the record of maintenance cost as a part of the routine of road upkeep.

Unit of Traffic.—Traffic should be recorded in units that will lend themselves to comparisons in widely separated areas. Since vehicles are of various weights and speeds and roadway surfaces are of various widths, the system of units should take these things into account. It would appear that each distinct type of traffic might be reported in tons or vehicles per annum per foot of width of roadway surface, which might be called the standard traffic units.

The traffic census is reduced to the terms of the standard traffic units and the average daily traffic and the annual traffic deduced from the census record and is reported together with the record of dates and hours of the census.

Some recapitulation forms for the traffic census are shown in Fig. 90 and in Table XXIX.

TABLE XXIX.—AVERAGE DAILY AND MAXIMUM HOURLY TRAFFIC AT SELECTED POINTS IN THE CITY OF CHICAGO

Station number	Station location	Average daily traffic					Maximum hourly traffic				
		Trucks	Passenger cars	Buses	Horse-drawn	Total	Trucks	Passenger cars	Buses	Horse-drawn	Total
101	Michigan Ave., bridge	.....	54,269	1,930	...	56,199	...	4,432	146	..	4,578
103	Michigan Blvd. at 35th St	.....	24,424	720	...	25,144	...	1,995	55	..	2,050
105	Jackson Blvd. between 5,000 and 5,100 block	.....	12,817	255	...	13,072	...	1,047	19	..	1,066
107	Garfield Blvd. east of Robey St	.....	17,540	213	...	17,753	...	1,432	16	..	1,448
109	Western Ave. north of North Ave	1,622	3,804	.....	208	5,634	97	311	...	23	431
111	Roosevelt Rd. at 4,600	1,375	3,618	.....	166	5,159	82	295	...	19	396
113	Wabash Ave. at 1542 S. Wabash Ave	4,500	9,774	.....	903	15,177	268	798			

Applications of the Traffic Census.—The traffic census serves as the basis for various estimates of the trend of traffic and as a means of reducing highway costs to a uniform basis for use in economic calculations. As before noted, it is not expected that the traffic census will do more than show the traffic at the time the census was taken. But with this information as a basis the engineer is able to forecast traffic within certain limits and thus proceed with plans that can be adequate for what seems to be the probable maximum requirements.

Volume of Traffic.—It is necessary to know the volume of traffic in order to design the width of surfaced road and to plan

BOROUGH OF MANHATTAN TRAFFIC COUNTS

LOCATION_____ BETWEEN_____ SHEET NO._____

DATE_____ HOURS TAKEN_____ WEATHER_____ TEMPERATURE_____

KIND OF VEHICLE	BOUND		BOUND		TOTAL		MAX. NO.	TIME
	NUMBER	TONNAGE	NUMBER	TONNAGE	NUMBER	TONNAGE		
HORSE DRAWN IRON TIRE								
" " RUBBER TIRE								
AUTOMOBILES								
STREET CARS								
AUTO TRUCKS								
AUTO BUSSES								
TOTAL								

PEDESTRIAN TRAFFIC	MAX. NO.	TIME	TOTAL NO.
SIDE BOUND			
SIDE BOUND			
SIDE TOTAL			
SIDE BOUND			
SIDE BOUND			
SIDE TOTAL			

WIDTH OF ROADWAY BETWEEN CURBS_____

WIDTH OF SIDEWALKS LEGAL _____ SIDE _____ SIDE _____

WIDTH OF SIDEWALKS ACTUAL _____ SIDE _____ SIDE _____

PAVEMENT_____ GRADE_____

MAX. NO. OF VEHICLES PER FT. OF WIDTH PER MIN._____

MAX. NO. OF PEDESTRIANS PER FT. OF WIDTH PER MIN._____

_____ SIDE _____ SIDE _____

FIG. 90.

means of relieving congestion. Volume of traffic is also an index to tonnage of traffic but weights may be determined as a part of the census. A knowledge of the volume of traffic will indicate whether the traffic is approaching the probable saturation point, as estimated by the ratio of the number of vehicles to the population in the area.

Weight of Traffic.—The record of weight of traffic enables the engineer to design roadway surfaces of sufficient strength for the probable loads. Generally, a small percentage of traffic approaches the legal maximum weight and perhaps exceeds it, which necessitates a design based on the legal maximum load. But in some areas the traffic units are considerably below the legal maximum, especially in the smaller cities.

It appears that economic comparisons of various kinds can best be made on a basis of relative weights of traffic although there is evidence that the destructive effect of vehicles is not wholly dependent on weight. There are many factors involved in the effect of traffic on road costs that cannot be evaluated in a traffic record in any case. Among these are the speed of the automobile, the skill of the driver, and the type and the condition of the tires.

It therefore seems most logical to base comparisons on weight as the best solution of a difficult problem.

Traffic Zones.—The traffic zone is mapped to show the system of highways that will be required in an area to serve traffic adequately. The cities are centers of traffic zones in which the highways must be developed according to some plan in order to care for the traffic in the most advantageous manner.

The traffic zone is mapped from results of traffic counts made throughout the area and the map so prepared serves as a basis for planning highway development. Since the effect of highway improvement is to increase the area tributary to a main market center and to increase the range of highway transport from industrial centers, the traffic zones will be fixed after a study of the existing traffic as shown by the traffic census and of estimates of the amount of potential traffic in the areas affected.

Such a study requires evaluation of many local conditions such as the type and extent of industrial or agricultural development, the size and character of the city, the proximity of scenic and recreational areas, and the climate.

All of these factors will be reflected in a traffic census but must also be considered in mapping the traffic zones for the area because of their effect on increasing traffic following the improvement of the roads in the district.

Problems

1. The annual cost of a certain road that is paved with a high-type surface is $1,600 per mile and the traffic averages 1,800 tons per day, mostly automobiles. Compute the annual cost of transportation on the road, in dollars per mile.
2. The records of the maintenance cost of a certain road surface have been checked over and the actual cost of maintenance computed at 5-year intervals. They are found to be as follows:
   During fifth year, $2 per mile per foot of width.
   During tenth year, $8 per mile per foot of width.
   During fifteenth year, $28 per mile per foot of width.

During twentieth year, $65 per mile per foot of width.

The pavement cost $2.50 per square yard and is estimated to have a salvage value of $1.15 per square yard. Interest at 5 per cent. Compute the economic life and the annual cost during the economic life of this pavement.

Useful References

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CHAPTER XXI

SELECTION OF TYPE OF ROADWAY SURFACE

The selection of the type of roadway surface is largely a matter of economic analysis for which only few fundamental data have as yet been established. The selection should be based on the principle of securing transportation at the minimum cost and no effort should be spared to find out what type of roadway surface will accomplish that in any community.

It certainly is not at present possible to determine transportation cost with absolute certainty in every administrative area and perhaps it will never be possible to do so. It is unlikely that the need for the exercise of good engineering judgment and thorough analysis of much technical data can ever be eliminated from the all-important problem of selecting the type of roadway surface.

Nor is it likely that the effect of the commercial promotion of paving materials can be wholly ignored. Since the administration of street improvements is largely political and that of rural highways is becoming more so every year, the engineer must reckon with political influences in the selection of types of roadway surface.

This presentation seeks to outline methods of selection that are perhaps more ideal than practical and are therefore inapplicable in many instances. On the other hand, the consideration of an ideal method may assist those who must perforce depart therefrom, to avoid the more serious breaches of good engineering.

Cost and Price Considerations.—The first step in the selection of the type of roadway surface, should be to determine, on the basis of current prices, the type that will give transportation service at lowest unit cost. If such a study results in any one type showing a marked superiority to the others considered, that is fairly positive evidence. A different type should be selected in such cases only under compulsion.

The cost comparisons may show that relative prices in a locality are such that several types of roadway surface will furnish

transportation at about the same cost. If that happens, the selection may be finally determined on the basis of physical characteristics of the pavement or from expediency.

Physical Characteristics of Roadway Surfaces.—Certain physical characteristics of roadway surfaces enter into the cost of transportation on that surface. Some such characteristics are, rolling resistance, rate of tire wear, smoothness, resiliency and rate and manner of wearing. The significance of these characteristics is included in proper cost comparisons.

Other physical characteristics are only partly covered or entirely excluded from any possible cost comparisons. These are principally of importance because of their reaction upon passengers in automobiles and busses.

Color.—The color of the roadway surface has some relation to the comfort of motor vehicle drivers. A type that glares or is harsh to the eye is somewhat less desirable than one that has a dead color and does not reflect light. This is perhaps a small factor.

Of more importance in high-class business or residence districts is the property of harmonizing with the surroundings. The black top pavements seem to be superior to the other types in this respect. In the locations mentioned the engineer would be justified in paying something for this characteristic.

General Appearance.—The general appearance of the pavement is dependent upon the physical makeup of the surface. Block pavements that are filled with a material of a color differing from that of the blocks, or a filler that wears off in irregular patches, do not have as pleasing an appearance as those of uniform color. The black, irregular streaks on concrete pavements that result from maintenance operations have been the occasion for much unfavorable comment, and illustrate the point. This consideration is of little moment in connection with the selection of surfaces for rural highways but would be of some importance on certain city streets.

Dustlessness.—The effect of the dust from earth, gravel or macadam surfaces upon the vehicle should be reflected in vehicle costs since the dust contributes materially to the cost of vehicle maintenance. But the effect of dust upon travelers is not reflected in any possible cost estimate. There is a distinct value to absence of dust, from the standpoint of the comfort of the traveler, although it would be exceedingly difficult to place a

money value on it. Under certain conditions the dust hangs over the roads in such clouds as to make driving exceedingly unpleasant and even dangerous. The traveler would certainly be willing to pay a cent a mile and perhaps more to be relieved of the dust. At any rate dust is inherent with some types of roadway surfaces which fact must be taken into account in the selection of types of improvement.

Ease of Cleaning.—The cost of cleaning is properly a part of the cost of pavement maintenance, although it is seldom so reported. It should be included in the cost items upon which relative costs are based and if that is done, no other account need be taken of the relative ease with which the several types can be kept clean and sanitary. To a limited extent the question of sanitation is involved in the selection of type of roadway surface. In the vicinity of markets, wholesale warehouses where perishables are handled, and in some dock districts, there will be considerable decayed matter scattered about on the pavements. If there are cracks or joints into which such matter can be packed, there results an odorous and unsanitary condition which is highly objectionable. In such locations some account must be taken of the ease with which certain roadway surfaces may be kept sanitary.

Character of Foothold.—Almost no attention is now devoted to providing good foothold for draft animals. In the United States self-propelled vehicles have so completely supplanted draft animals that one scarcely thinks of the animal-drawn traffic in connection with the selection of types of roadway surface. In an area where there is an amount of animal-drawn traffic there should be a selection of type suitable to this class of traffic especially for roads or streets on grades. Good foothold means either a very granular texture of surface or cracks or grooves in the surface. Good foothold is provided by several common types of roadway surfaces.

SPECIAL LOCAL CONSIDERATIONS

In some few instances the engineer will be confronted with the problem of selecting the type of roadway surface in the face of local conditions of a special nature or those urged upon him as special. The problem is not difficult in such cases if the cost (not price) is adversely affected but when that is not the

case or when little difference exists in cost, some embarrassing situations arise.

Local Materials.—If local supplies of road material are commercially available, that fact is likely to be reflected in the prices of the various types of roadway surfaces. When cost comparisons have been made, the influence of local materials has already been included, but sentimental reasons are sometimes urged in favor of local enterprise. Properly so in many cases. Undeveloped local supplies of material do not appear as a factor in any cost analysis unless effort is made to have them considered and a basis of development arranged. A contractor cannot base his bid on the use of local gravel or other material, unless he knows that the material is of acceptable quality and will be made available in ample quantities at a prearranged price. It is the task of the engineer to ferret out the local materials and make sure that the cost analysis takes account of them.

Existing Types.—There is some advantage in having a single type of roadway surface in an administrative unit but the probability is that when it becomes generally known that a city or a state favors this or that type, the price thereof will gradually increase. The best policy to pursue seems to be to accept either of two types of roadway surface of such character that they are inevitably always in competition. The maintenance organization and equipment is simplified somewhat by confining the types to a few classes. No sacrifice in cost is warranted in order to keep a system of highways uniform in type, but where no appreciable difference in cost exists between several types, it is advantageous to standardize on two of them.

Maintenance Organization.—All of the states have developed, or are now developing, competent maintenance organizations and can maintain any of the types of roadway surface. A good many counties and cities also have competent maintenance organizations but on the other hand the great majority of the smaller cities, the townships and the counties seem unable to accomplish timely and proper maintenance. There is no type of roadway surface that will give maximum serviceability when maintenance is neglected, but some types withstand abuse better than others. This fact needs to be taken into account frequently when types of roadway surface are being selected.

Recapitulation.—The selection of the type of roadway surface is primarily a problem of estimating which available and accept-

able type will furnish transportation service at the lowest cost. Where there is a markedly lower cost for any particular type it should generally be selected.

In arriving at the estimated cost of transportation there should be consideration of every type of roadway surface that is suitable for the location.

In rather frequent instances it will be found that the cost of transportation will be nearly identical for several types of roadway surface. In such instances the selection may be based on considerations other than cost.

A few characteristics of certain types of roadway surfaces are not reflected in the cost of transportation on those types. The engineer must arbitrarily evaluate such characteristics if one of these types is economically desirable.

CHAPTER XXII

MAINTENANCE

Maintenance of a highway consists in performing such repair operations as are needed from time to time to keep the surface up to maximum serviceability and to prevent abnormal deterioration of supplementary appurtenances such as guard rails and sign posts. In some instances maintenance becomes so extensive and elaborate as really to constitute reconstruction, but such work is not included under the ordinary interpretation of maintenance.

When a roadway surface of any kind is completed for traffic, it is assumed to possess the maximum serviceability for that type of construction. Deterioration will begin immediately and progress at an accelerated rate until the surface reaches its economical life. During this period the wearing surface should be kept in good repair by the operation of a system of maintenance in order to insure the maximum economical life. The amount and kind of maintenance work needed will depend upon the kind of surface, the volume and character of the traffic, the climate and the age of the road surface.

It is an established practice in many cities to require the contractor who constructs a roadway surface to maintain that surface for a period varying from 5 to 7 years. This is sometimes indirectly through a guarantee clause. Compliance with the guarantee or maintenance provision is enforced through a bond filed by the contractor and drawn to cover the specification requirements relative to maintenance. This system originated when certain new types of pavement were being developed and public officials did not have a means of judging as to the probable serviceability of the proposed types. The promoters were willing to guarantee the product in order to secure contracts and the system thus developed.

At present the requirement that the contractor must construct the pavement in accordance with the engineers' specifications and then guarantee the results, works a manifest injustice which is reflected in the price paid for the work. It is believed that a

guarantee should cover only a short period of time, such as one year, and should be drawn to protect the public from dishonesty in the construction. It should not include a maintenance provision.

The cost of maintenance cannot be predicted with any degree of certainty for several reasons. The most important item in establishing the cost of maintenance is the volume and character of the traffic that will use the highway, but it is almost impossible to foresee the traffic developments on a paved surface. The cost of labor also fluctuates greatly, and cannot usually be estimated several years in advance. The same is true of the cost of materials. For these reasons, to require a contractor to include in his bid a provision that he will maintain the surface for a period of years after its construction, usually results either in inadequate maintenance during the period or in loss of money to the contractor.

After a pavement has passed beyond the guarantee period the city must maintain it and this work may be done by contract or by force account. Both methods are used but force account maintenance is growing in favor.

The guarantee method of maintenance has never been extensively employed in connection with rural highways, and force account maintenance is being generally adopted. For some classes of maintenance work it has proven advantageous to employ the contract method.

MAINTENANCE OF RURAL HIGHWAYS

Organization.—Nearly all state highway organizations include a maintenance department which has general supervision of all maintenance activities in the state. The highways to be maintained are divided into patrol districts including from 5 to 15 miles of highway, and a patrolman is employed to perform all maintenance work on the highways in his district. The amount of road that one man can care for will vary with the type of surface, the amount of traffic and the climatic conditions.

In addition to the work done by the patrolmen, there will be some general repair work that requires a crew of several men and extensive equipment. For work of this latter class maintenance gangs are organized with the proper personnel and suitable equipment for each class of work that is performed by the gang.

Patrol Maintenance.—This system of maintenance is regularly employed for every type of roadway surface that is constructed on rural highways. The patrolmen need not be experienced in highway work when they begin their work, but must have some knowledge of the way road machinery is handled, and must be

FIG. 91.—Types of guard fence.

wide awake and possess a reasonable amount of initiative and common sense. They are usually employed for about 7 mo. in the year in the northern states and 1 to 2 mo. longer in the south. For earth, sand-clay and gravel surfaces, a team is necessary for dragging and grading, as there are rainy times when work should be done when the tractor cannot be used. The patrolman must furnish his own team if one is to be used. If the road surface is bituminous macadam, asphaltic concrete, sheet asphalt, brick or concrete, it is entirely practicable to employ motor trucks for hauling all supplies and for dragging the earth shoulders. The patrolman may also use a light truck for traveling over his district but that would not be an efficient use of the truck.

Equipment of Patrolmen.—For earth, sand-clay and gravel roads the patrolman would be equipped with the following tools and machinery:

1. A light road grader suitable for one team.
2. One or two steel or split log drags.
3. One or two road planers, such as the Minnesota planer.
4. One slip scraper.
5. One wheel scraper.
6. One plow (sometimes).

FIG. 92.—Road patrol equipment.

7. One team with dump wagon.
8. Picks, shovels, grubbing hoe, axe, scythe, measuring tape, paint brushes, sign stencils.
9. Small kit carpenter tools.
10. Manual of instructions and report blanks.

For broken stone macadam, which is being maintained without a bituminous treatment, the following would be required:

1. A light road grader suitable for one team.
2. One split log or steel drag.
3. One slip scraper.
4. One team with dump wagon.
5. Picks, tampers, napping hammer, grubbing hoe, axe, scythe, measuring tape, paint brushes, sign stencils.
6. Small kit carpenter tools.
7. Manual of instructions and report blanks.

For maintenance of roads upon which the wearing surface is one of the types of bituminous surfaces, or surfaces upon which bituminous materials are employed for filling cracks, the following equipment would be required:

1. A light grader suitable for one team.
2. A split log or steel drag.
3. One slip scraper.
4. One team with dump wagon.
5. One portable kettle for heating bituminous material.
6. One pouring pot for bituminous material.
7. Picks, shovels, rakes, tampers, grubbing hoe, axe, scythe, measuring tape, paint brushes and sign stencils.
8. Small kit carpenter tools.
9 Manual of instructions and report blanks.

The lists of equipment given above are intended to provide for the care of the side road and ditches, guide posts, guard rails, bridge floors and the wearing surface. Some items are omitted in specific cases and others added, but the lists show the ordinary equipment. Everything is provided of such a character that one man can do all of the work on his section of road. In some cases where the patrol district is made up entirely of earth roads, the patrolman is permitted to employ assistants to aid in the dragging under proper restrictions. The patrolman may also be permitted to rent a mowing machine to use in cutting weeds.

Patrolling Earth Roads.—The first duty is to maintain a smooth surface for traffic. This is accomplished by first smoothing with a light grader and then by dragging repeatedly with a plank or steel drag. Usually the grader must be used when the roads are settling after the spring rains, and after that the drags are adequate. The whole problem is to keep the surface smooth and free from depressions that will hold water.

The ditches must be kept clear of obstructions so that they will drain freely. This is done by cleaning out with a blade grader and then cutting the weeds two or three times a year. Small obstructions can be removed with the shovel. Where erosion of storm water has removed a part of the side road or the berm on fills, the earth is returned with the slip or wheel scraper and carefully placed and tamped.

The waterway at the ends of the culverts is cleared of weeds or trash two or three times a year, and the catch basins on the tile lines are also cleared twice a year.

Weeds are cut at least twice a year and if this is adhered to good sod will usually replace the unsightly weeds. Where the topography permits, a mowing machine is employed for this purpose, but in many places the scythe will have to be used. Brush, weeds, or low-hanging limbs to trees that might obstruct the view at the turns, should be cut frequently.

Guard rails, warning signs, and road signs or markers should be painted as required to keep them in a good state of preservation and any repairs required should be made promptly.

Patrolling Surfaced Roads.—The duties of the patrolmen are similar to those imposed upon patrolmen on earth roads except that the methods differ so far as upkeep of the wearing surface is concerned. On gravel and sand clay surfaces the principal work will be done with the light blade grader and the drag and planer, but new surfacing will be required in places. This is added while the road is wet so that it will bond to the old surface. In order to keep such surfaces up to the maximum serviceability continual work is required.

With surfaces consisting of a bituminous carpet coat, the patrolmen patch the surface with bituminous material whenever a break occurs in the surface. The spot is thoroughly cleaned, new material heated and spread and the patch covered with stone chips to keep the new material from sticking to wheels. In some cases it may be necessary to remove depressions by adding stone to a small area of the surface. When this is to be accomplished the area affected is loosened with a pick to secure a bond between the old and the new material. The new stone is placed and tamped, coated with bituminous material and covered with chips. If the patch is thin, it is well to coat the bottom of the depression thoroughly with bitumen before the new material is placed.

For repairing surface such as sheet asphalt or asphaltic concrete it is desirable to have available the equipment for preparing the proper mixture of aggregates and bitumen at suitable temperatures. This sort of equipment cannot be furnished to patrolmen, and repair work on hot mixed pavements is usually carried out by special gangs.

Temporary repairs are often accomplished by mixing small quantities of stone and a suitable binder by means of a shovel. Sometimes the binder is used cold and sometimes hot, but the material after mixing is stored until required and is placed and tamped cold.

In order to insure that a patch will not be displaced by traffic it is necessary to remove the old wearing surface over the area affected, down to the base course. The sides and bottom of the hole, which should be roughly circular in form rather than square or rectangular, should be coated with the bituminous material before the new material is placed. The hole is filled and the material thoroughly tamped. The surface is coated with bituminous material and covered with stone chips.

The principal maintenance work on brick or concrete wearing surfaces consists in filling the cracks with a suitable bituminous filler. This is necessary once or twice a year and may be done either by the patrolman or by special gangs. The work consists in carefully removing dust or sand from the cracks, if they contain such material, and then filling with a bituminous filler.

With all types of surfaced roads the side roads, ditches, guard rails, bridges, signs and waterways must be cared for in the same manner as with earth roads, and this work is most readily accomplished by patrolmen.

GANG MAINTENANCE

Some classes of repair work can most economically be accomplished by special gangs, and this is especially true of those operations requiring several men to insure rapid and efficient work. The size of the gang and equipment provided depends entirely upon the work to be done.

Gang Maintenance on Earth Roads.—The work outlined in Chap. V, as involved in the construction of an earth road, is for administrative purposes sometimes classed as grade reduction work or construction and other times as grader work or maintenance. The grader maintenance is accomplished by special

gangs organized and handled as described in the chapter referred to. For this work a tractor, one or two graders, a team and wagon and about four men constitute the gang.

Gang Maintenance on Gravel and Macadam Roads.—When it becomes necessary to resurface roads of this character, special gangs are employed. The equipment consists of the following:

1. One macadam roller.
2. One sprinkling cart.
3. One scarifier.
4. One heavy harrow.
5. One light grader suitable for one team.
6. Teams and dump wagons for hauling material.
7. Shovels, picks, stone forks, rakes as needed.

The work consists in thoroughly loosening the old material by means of the scarifier, harrowing to bring up the coarser material, adding new material to give the desired thickness, and rolling and bonding the surface with water.

If the maintenance consists in applying a bituminous carpet coat to the surface, special equipment will be required for that work.

Oil Storage.—If any regular use of road oil is made it will be advisable to provide one or more tanks for storage of oil, and these should be of sufficient capacity to hold a tank car of oil. The tank may be on the ground or under ground, or it may be elevated so that the distributing tank can be filled by gravity. If heavy oils are used the tanks must be equipped with steam coils for heating the oil.

For distributing the oil, motor-driven tank trucks or horse-drawn trucks are suitable. If the oiling operations cover a large mileage the motor truck is necessary in order to speed up the work.

The surface of the road will be cleaned with a rotary broom street sweeper, supplemented by hand sweeping.

Teams with dump wagons will be needed for hauling the chips used for dressing the surface.

The work consists in thoroughly cleaning the surface by sweeping first with the power broom and then finishing with the hand broom to remove pockets of dust missed by the power broom. The bituminous oil is then spread and covered with coarse chips.

Gang Maintenance on Sheet Surfaces.—When extensive repairs become necessary on sheet asphalt or asphaltic concrete

surfaces, it is necessary to have a plant for mixing the materials comprising the surface. The equipment would consist of the following:

1. A small plant for preparing bituminous mixtures.
2. One tandem roller.
3. Wagons or trucks for hauling the hot mixture.
4. Axes, shovels, rakes, smoothing irons and tool heater.
5. Portable kettle for heating bituminous cement.

FIG. 93.—Gang maintenance of paved surfaces.

The road is inspected and the area to be repaired at each break in the surface is marked. The existing surface is removed down to the base. New material is mixed, spread in the holes and rolled. If it is an asphaltic concrete the surface is painted with asphalt cement and covered with stone chips or sand.

Gang Maintenance on Brick and Cement Surfaces.—Sometimes gangs are organized to fill the cracks in these surfaces

instead of requiring it to be done by the patrolman. The equipment required is the same as that furnished the patrolmen for similar work. The crew generally consists of a foreman and three or four laborers. One team will be required to haul materials. The work done is identical with that of the patrolman on similar surfaces.

SNOW REMOVAL

In areas of considerable snowfall an increasing amount of attention is being paid to removing the snow from the traveled part of the road or packing it down so that traffic will not be impeded. No one method has as yet been adopted for this work, but the following methods have been used with some success.

Snow Plows.—One type of snow plow is a V-shaped drag drawn by a tractor. It removes the snow for a width of about 12 ft., but several trips are required where the snow has drifted and laborers are required to pile back the snow from the cut in deep drifts.

Another type of snow plow is pushed ahead of a truck and by making successive trips a track of any desired width can be made. Usually a track about 15 ft. wide is cleared.

A third type of snow plow is built after the design of the rotary plow used in railroad service and is identical in operation, but of course much smaller. It is pushed by a truck or tractor.

Usually there is combined with each of these methods a certain amount of hand shoveling to clear the heavy drifts. The use of snow fences is also being adopted to some extent.

MAINTENANCE OF STREETS

The maintenance of streets involves the upkeep of the pavement, where the street is paved, the maintenance of unimproved streets, the cleaning of the streets including the removal of snow in those cities where snowfall is of sufficient volume to impede traffic, and the inspection and cleaning of the inlets and catch basins in the storm sewer system. In many cities the removal of ashes and other refuse is accomplished by the organization that is responsible for the other activities mentioned, but that problem will not be discussed herein.

Pavement Repairs.—Pavement repairs are sometimes made by the contractor who constructed the pavement, under a

maintenance provision of his contract, and while such repairs are usually performed under the supervision of the city engineering department, the methods of actually doing the work vary with the contractor. The discussion herein refers more specifically to the repairs made after the city takes over the pavements for maintenance.

Nearly all cities use the gang system rather than the one man patrol system in making pavement repairs, due primarily to the fact that the types of pavements that predominate do not lend themselves so readily to patrol methods, and due also to the fact that as a rule it is desirable to expedite the work so as to occasion the minimum inconvenience to traffic. The maintenance gangs are usually organized for work on a particular type of pavement and work the entire season on that type. This simplifies supervision and the problem of equipping the gangs.

Repairs are made in the manner described in the discussion of the construction of the several types in preceding chapters.

For the bituminous sheet pavements the prepared mixtures for the patching may be purchased under a contract or they may be prepared at a municipal plant. Cities that have a large area of sheet pavements to maintain generally find it advisable to operate a municipal plant as it gives the city better control over the time and rate at which the work is done.

It is the usual practice to begin the repair work as soon as the season will permit and to continue at a rate that is estimated to insure completion of the projected work during the season. Openings made in pavements to reach service pipes are usually repaired by the utility company making the opening, but the replacement is under the supervision of the street department. In order to control the work, permits are required before openings can be made. This applies to plumbers as well as to public utilities.

Unimproved streets are also maintained by gangs and the work consists in smoothing the streets two or three times a year by means of blade graders, and in maintaining the smooth condition as well as may be by the use of the drag. The methods follow very closely those adopted for similar work on rural highways.

Dust Suppression.—The suppression of dust has become an important problem for sanitary reasons and for reasons of cleanliness. On unimproved streets one or the other of the following

methods are usually followed: suppression by sprinkling with water and suppression by means of light petroleum oil.

Street Sprinkling.—Water sprinkling has been widely practiced for years both on unimproved streets and on gravel, macadam and even on high-class pavements. When the cost of the water is considerable this method is expensive, and in any case it is of low efficiency. The effect of sprinkling lasts but a few hours in hot weather and is never entirely satisfactory. Immediately after sprinkling, the street is likely to be sloppy and in a few hours, dusty.

Sprinkling with oil, or road oiling, has been fully discussed in a previous chapter.

Cleaning.—It has come to be generally recognized that the best prevention of dust is through efficient cleaning, but this method is only available where the streets are paved with a fairly smooth pavement.

STREET CLEANING

Sweeping.—One method of cleaning is to sprinkle and sweep the streets at frequent intervals. The work may be done nightly, as would be necessary on busy streets, or it may be done less frequently on residence streets. Sometimes the interval between cleanings is as great as 2 weeks or even a month. The street is sprinkled and immediately swept by a power sweeper, the sweepings being left in the gutter to be picked up by another gang. In busy districts the work is done at night and the cleanings are all removed before daylight. In residence districts the work is done by day.

For smooth pavements such as wood-block and sheet pavements a rubber squeegee is used instead of the broom on a power machine. This method results in a cleaner pavement than can be secured with the broom but the method cannot be used on block pavements because the squeegee will not remove dirt from the cracks and uneven places.

Recently a power cleaner operating on the principle of the vacuum cleaner has been developed and seems to be preferable to any other method devised, because the sweepings are entirely removed from the street at one operation.

Flushing.—Cleaning by flushing with water is widely employed and the method consists in washing the pavement with a stream of water from a pressure tank, or a stream from a pump con-

nected to a tank. The jet of water flushes all of the dirt to the gutters and most of it is carried into the storm sewers and thus disposed of.

Hand Sweeping.—In order to preserve through the day the cleanly condition of the streets, patrols, the familiar "white wings," go over the pavement repeatedly, removing papers, trash and droppings and placing them in iron receptacles placed at convenient points. These are emptied daily. Each patrolman works in a fixed area and usually works alone.

CLEANING DRAINAGE ACCESSORIES

The catch basins and inlets to the storm sewers are cleaned several times a season, or as often as refuse accumulates therein. The amount of labor involved in this task is enormous in a city of any size, and the tendency in the design of these accessories is toward a type that is self-cleaning.

SNOW REMOVAL

The problem of snow removal is a serious one on the busier streets of those cities that experience considerable snowfall.

The snow is removed by special gangs recruited for the purpose, supplemented by the work of the regular street-cleaning forces. The snow is scraped to the gutters by snow plows and loaded onto trucks, or is shoveled directly from the street into wagons or trucks. It is then hauled to vacant lots or streams and dumped. In a few cities the snow is dumped into special traps connected with the sewers and thus disposed of. In other instances the snow is removed fron the busy streets and stacked in the side streets where it is expected to melt and thus be disposed of. In cities such as New York and Chicago elaborate and comprehensive plans are worked out for removing the heavy snowfall to which those cities are subjected. Trucks, snow plows, snow-loaders and enormous forces of snow fighters are recruited for the work and the organization for handling the forces is complete and effective.

EXAMPLES OF GOOD PRACTICE

Patrol System for Pennsylvania Road Maintenance[1]

Each patrolman will be supplied with tools and equipment necessary for his work and each one will have a small red flag

[1] *Engineering and Contracting*, Sept. 10, 1917.

which he will be required to place in a conspicious position on the road when, for any reason, he is required to leave the roadside during working hours. Hence, either the presence of the patrolman at work or of his flag, indicating temporary absence, will be noticeable during the working hours.

Great care is being exercised in the selection of these partolmen and State Highway Commissioner Cunningham is determined to have none but sober, honest and industrious men in these responsible positions. If it is found that the patrolmen are neglecting their work instant dismissal will follow.

The manner in which the caretakers will work is as follows: Along the side of the highway at frequent intervals will be placed small piles of stone chips and gravel, which will be used in patching holes as they are found in the roadway. Barrels, or drums, of bituminous material, containing approximately 45 gal. each, will be placed at intervals of from ¼ to ⅓ mile along the roadside. When the caretaker finds a spot in the road which shows signs of wear he will place the stones and bituminous material in it, tamping it down carefully and making the surface of the road smooth and even The caretaker also will look after the edges of the road and will keep the berms clear of weeds and grass and will protect the shoulders of the road to prevent water from getting underneath.

Each patrolman will be supplied with the following outfit: A small combination melting and pouring pot on wheels, a hand-pouring pot, an asphalt tamper, a wheelbarrow, a push brush, a pick, a short-handled and a long-handled shovel, a scythe and a snath, a mattock, a rake and a brush hook.

As the patrolmen will be under the constant watch of the county superintendent, it will be necessary for them to devote their entire time and attention to the territory to which they are assigned. It is the intention ultimately that no man shall have more than 6 miles of roadway to patrol, and this only in sections where the character of the road is such that he can cover it easily and conveniently in a day. In mountainous districts, and in places where peculiar formations make the care of the road more onerous, the patrol distance will be diminished.

SPECIFIC DUTIES OUTLINED

The following list of the general duties of the patrolmen has been prepared by the State Highway Department and each

man, as he is engaged, will be furnished with a copy of it and will have his duties explained to him in detail.

Keep drains and ditches open at all times.

Special attention must be given to defects in planking and condition of bridge floors.

Repairs all defects in the surface of the road, maintaining same in a true and even condition.

Repair and whitewash guard rails.

Provide protection and red lights in cases of flood washouts, or other emergency conditions.

Remove brush from along the sides of the road, giving special attention to this condition at curves, approaches to railroad crossings, bridges, cross-roads, etc.

Keep the berms or shoulders of the road trimmed up, in that the surface water may be discharged freely from the road surface to the side ditches.

Remove all advertising signs from within the legal limits of the highway.

Paint and keep in first-class condition all department direction and warning signs.

Inspect culverts, head-walls, cribbing, retaining walls, etc., and report defects immediately to the superintendent.

Whitewash large rocks and the bases of poles on narrow sections of highway and at sharp curves. (Spring and fall.) Poles to be whitewashed to a height of 6 ft. above ground.

All equipment, tools and material placed in the charge of each caretaker must be accounted for by him at all times, and tools and equipment kept in thorough repair.

Economic and workmanlike results will be the most important factor recognized by the department.

Attention must be given to the entire section allotted to the caretaker, and work not confined to special and convenient portions.

Daily report postal card must be mailed every evening to the superintendent.

When working on the road caretaker must have flag, which will be provided, displayed at all times near where work is being performed.

When conditions require additional help, team hire, or material of any character, permission must be first secured from the superintendent.

All additonal help and team hire must be carried on foreman's daily report form, together with regular pay roll form, etc.

All bills for materials, etc. in amounts less than $10, must be covered by superintendent's purchase order: larger amounts by requisition of superintendent and department purchase order.

Caretakers must be courteous and considerate of the interests of the public at all times, and conduct themselves in a manner becoming representatives of the commonwealth.

Sobriety, honesty, industry, good character, and ability are the essentials required, and a failing in any of these will be met by dismissal.

Methods of Snow Removal from Highways[1]

The insistent demands of modern traffic have made necessary the removal of snow from the surface of highways in undustrial and commercial areas. Efficient methods of keeping these highways open in winter were outlined by Charles J. Bennett, State Highway Commissioner of Connecticut, in a report submitted Feb. 28 at the annual convention of the American Road Builders' Association.

In order to make a study of snow removal, the general conditions which govern the amount and character of the snow to be removed must be carefully considered. These may be classed as follows:

Geographical Location of the Section.—This determines the amount of annual snowfall, and the approximate greatest fall per storm which must be taken care of; also the usual moisture content, which is a large factor in determining the amount of equipment needed. In defining this general class further, for convenience we may consider three subdivisions:

(*a*) Locations where the total depth of any one storm is not over 9 in., and the total snowfall not over 3 ft.

(*b*) Locations where the total depth of any one storm is not over 18 in., and the total snowfall not over 3 ft.

(*c*) Any location where conditions are more severe.

Local Conditions.—These are the usual cause of excessive accumulations of snow at any given point. The general direction of the road combined with the prevailing direction from which the snow drives, causes much difference in the depth of snow to be removed. A side-hill location, or location of a road in a cut, will cause the accumulation of snow in the traveled path. Stone walls, fences and untrimmed brush hedges which may run along the roadway, form the most usual cause of drifts. A study should be made with the purpose of eliminating, as far as possible, any special accumulation from these causes. Hedges may be trimmed, walls removed, and snow fences installed. This work,

[1] *Engineering-Contracting*, Mar. 5, 1919.

properly carried out, will eliminate the formation of many drifts. If nothing can be done to prevent the formation of drifts, special efforts should be made to handle this accumulation locally without leaving it to the equipment which handles the bulk of the work.

The removal of snow is particularly congested districts, such as city streets, is a special problem which requires an entirely different equipment from the general snow removal on highways. Under these conditions special studies should be made of local conditions, as the bulk of the snow has to be picked up and moved away from the streets themselves.

The location on the travel-way of the trolley tracks, from which the traction companies remove the snow by plows, necessitates about double the amount of snow removal from the remaining portion of the road surface. This usually occurs in thickly populated districts, but often occurs on interurban lines between towns. Equipment necessary to handle this class of work will have to be about double that of the ordinary work. Arrangements should be made to have extra equipment at these points to assist the regular snow-removal equipment, so that it will travel at approximately the same rate of speed as if the trolley tracks were not there; similar to the local arrangements made where drifts cannot be prevented. If this is done, the problem is simplified and resolves itself into the selection of equipment suitable to handle the greatest average fall in any one storm, for the section in question.

Classification of Roads for Snow-removal Purposes.—After determining the amount and character of snow liable to occur, it is then necessary to classify the roads as to the speed at which the work must be handled; the amount of snow to be left on the road and the width to which the snow should be removed, so that the prevailing class of traffic may use the highway with safety. For this purpose there are, roughly, three classes into which the roads may be divided:

1. Those which carry heavy motor-vehicle traffic.
2. Those which carry a small percentage of motor vehicles and a large percentage of horse-drawn traffic.
3. Those which carry a negligible amount of motor traffic, the delay to which should not cause serious hardships.

Under the first class, the snow must be removed as rapidly as possible from the complete width of the roadway surface. The local conditions in this class of road are almost always bad. They usually run through fairly well built-up sections, where snow

fences are not practicable, and where under the most severe conditions some snow must be moved. Under these conditions, any snow which must be moved clear of the roadway should be handled by a local organization, allowing the regular equipment to proceed with their work, which should be limited to taking care of the free passage of traffic.

In the second class the snow need not, necessarily, be completely removed, and the speed necessary for the first class need not be maintained. About 4-in. depth of snow can be left on the road to take care of the horse-drawn traffic, and the width should be sufficient for the safe passage of vehicles, with the possible exception of deep drifts, where the removal to this width would cause an unnecessary expense.

Selection of Snow-removal Equipment.—In selecting the equipment to be used, it is necessary to bear in mind the general classifications as well as the classifications according to traffic. In general in Class A, which includes storms up to 9 in. in depth, it has been found that the use of a plow attached to the front of a motor truck will operate to advantage, and is almost absolutely necessary where speed is the deciding factor, as on the roads carrying a heavy auto traffic. These trucks may be also used to supplement the equipment used on the secondary roads, should they not be sufficiently clear by the time the main roads are finished. Road machines and plows operated with horses may be successfully used on the secondary roads, supplemented as above, by trucks.

CHAPTER XXIII

ROAD MATERIAL TESTING

There are many materials employed in road construction that are even more generally used for other types of construction, and to present herein the methods of testing accepted for all materials used in road work would serve no useful purpose. It is thought desirable, however, to include a brief description of those tests to which the highway engineer has most frequent occasion to refer, and to discuss some matters of general interest to the engineer who has occasion to test materials or to prepare specifications in which tests are referred to.

The American Society for Testing Materials has been the agency most active in the standardization of methods of testing, and so far as that society has covered the field, its methods are most widely accepted by both producers and consumers of construction materials. The society's standard and tentative standard methods of testing are printed in leaflets that can be purchased at trifling cost, and these should be in the library of every engineer who deals with road materials in any way. Several years ago the American Association of State Highway Officials constituted a Committee on Tests and Investigations, and the membership of that committee is made up of engineers and chemists from the testing departments of state and federal highway departments. This committee has selected the tests it considers best for the purpose of checking and controlling the quality of materials used in state highway construction. To a large extent the committee has recommended the use of the methods that have been worked out by the American Society for Testing Materials, although minor modifications have been suggested for some of the methods.

The methods of testing presented herein are those recommended by the Committee on Tests and Investigations, and may be found in the publications referred to, where more complete descriptions of the method, and sometimes illustrations of the apparatus, are given.

METHODS OF PROPORTIONING CONCRETE AGGREGATE

Crum's Method of Proportioning Concrete Aggregates.—It is coming to be recognized that the engineer must deal with two classes of concrete aggregates, *i.e.*, those that may be termed standard or ideal aggregates as regards their sieve analysis, and those that depart in some degree from the standard.

Standard concrete sand is of such size that at least 95 per cent. will pass a sieve having openings 0.185 in. square and not to exceed 5 per cent. will pass the standard 100-mesh sieve. Between these two sizes the gradation is fairly uniform.

Standard coarse aggregate is of such size that at least 95 per cent. will pass a screen having openings 2 in. square and not to exceed 5 per cent. will pass a sieve having openings 0.185 in. square. Between these two sizes the gradation is fairly uniform.

With aggregates of these sizes, assuming them to be sound and clean, there are three mixtures that have been widely used and that give concrete of fairly uniform strength for each mixture, when the right quantity of water is employed. They are as follows:

Class 1.—One part cement, 2 parts sand, and 3½ or 4 parts of coarse aggregate, producing concrete having a strength in compression of 3,000 to 4,000 lb. per square inch at the age of 28 days.

Class 2.—One part cement, 2½ parts sand, and 5 parts of coarse aggregate, producing concrete having a strength in compression of 2,000 to 2,500 lb. per square inch at the age of 28 days.

Class 3.—One part cement, 3 parts sand, and 6 parts of coarse aggregate, producing a concrete having a strength in compression of 1,000 to 1,500 lb. at the age of 28 days.

In order to facilitate the proportioning of mixtures (usually unscreened gravel) containing a higher percentage of sand than the three mixtures just described, R. W. Crum[1] prepared, after long experimentation, the three diagrams shown in Fig. 94. In proportioning the concrete by means of these diagrams, first determine the weight per cubic foot of the mixture of sand and coarse aggregate that it is intended to use. The diagrams are based on the weight of loose materials and this condition is approximated by allowing the point of the shovel to rest on the measuring vessel (a cubic foot box or a cylindrical measure having a capacity of not less than ½ cu. ft) and allowing the material to slide off the shovel into the vessel. Without any further tamping

[1] Crum, R. W., Director, Highway Research Board, Washington, D. C.

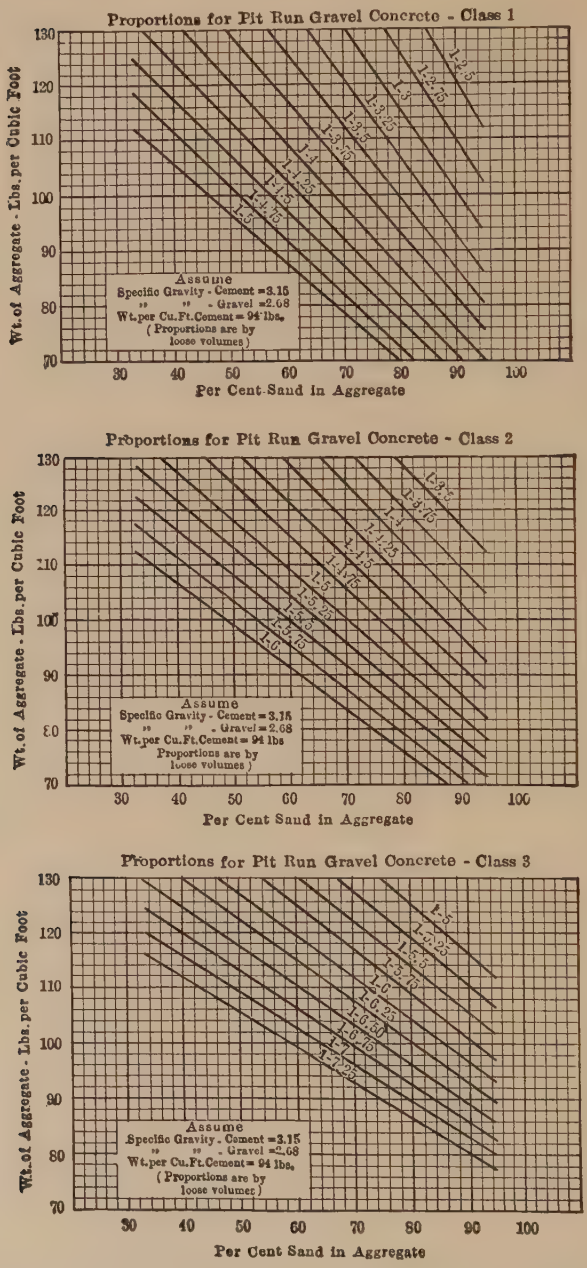

FIG. 94.—Illustrating method of proportioning mixer aggregates.

or compacting the weight per cubic foot is determined. The percentage of sand in the proposed mixed aggregate is then determined, either by volume or by weight, since these are nearly the same for mixtures of this class, and the proportions of cement to aggregate determined from the diagram that applies to concrete of the desired class.

Abrams' Tables of Proportions.—When either the coarse aggregate or the sand, or both, depart from the sizes usually considered standard, concrete of any desired strength may be produced by properly proportioning the mixture. D. A. Abrams[1] has worked out a table for producing concrete having a strength in compression of 3,000 lb. per square inch at the age of 28 days, which is based on his investigations at the structural materials laboratory of Lewis Institute. This is the strength usually required for portland-cement concrete roadway surfaces and the table is intended primarily for proportioning concrete for that purpose. It is reproduced herein as Table XXX.

STANDARD SIEVES

For Asphalt Pavement Mixtures.—For performing the sieve analysis on the mineral aggregate for sheet asphalt mixtures and the finer portion of the mineral aggregate for asphaltic concrete mixtures, the set of sieves listed in Table XXXI has been adopted as standard by the American Society for Testing Materials.[2] It should be obvious that a report of a sieve analysis cannot be interpreted unless the exact dimensions of the sieve openings are known. Care should be taken in equipping a laboratory to make sure that the sieves comply with the standard. They can be purchased from any dealer in laboratory apparatus.

[1] ABRAMS, D. A., Director of Research, International Cement Corporation, New York.

[2] See A. S. T. M. Standard Method of Mechanical Analysis of Sand or Other Fine Highway Material, *Serial Designation* D 7, 18.

Table XXX.—Abrams' Table of Proportions and Quantities for 1 Cu. Yd. of Concrete

Based upon laboratory investigations, using approved materials, compressive strength, 28 days, with workable plasticity, 6 by 12-in. cylinder, 3,000 lb. per square inch.

Sizes		Fine aggregates, screen openings per inch														
Coarse aggregate, inches	Cement in barrels aggregates in cubic yards	0–28			0–14			0–8			0–4			0–⅜ in.		
		Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse
No. 4 Screen to ¾	Proportions	1	1.3	2.4	1	1.6	2.4	1	1.8	2.3	1	2.0	2.3	1	2.7	1.5
	Quantities	1.96	.37	.69	1.85	.44	.66	1.82	.48	.62	1.75	.52	.59	1.79	.72	.40
No. 4 Screen to 1	Proportions	1	1.3	2.7	1	1.6	2.6	1	1.8	2.6	1	2.0	2.5	1	2.6	1.8
	Quantities	1.90	.36	.76	1.77	.42	.68	1.72	.46	.66	1.67	.50	.62	1.72	.66	.46
No. 4 Screen to 1½	Proportions	1	1.2	3.1	1	1.6	3.2	1	1.7	3.1	1	2	3	1	2.4	2.4
	Quantities	1.82	.32	.84	1.68	.40	.79	1.63	.41	.75	1.61	.47	.72	1.62	.57	.57
No. 4 Screen to 2	Proportions	1	1.2	3.5	1	1.5	3.5	1	1.6	3.7	1	1.9	3.6	1	2.2	3.1
	Quantities	1.75	.31	.90	1.63	.36	.85	1.55	.36	.85	1.52	.43	.81	1.53	.50	.70
No. 4 Screen to 2½	Proportions	1	1.1	3.8	1	1.4	3.9	1	1.6	4.0	1	1.8	4.0	1	2.1	3.5
	Quantities	1.72	.28	.97	1.58	.33	.91	1.51	.35	.89	1.49	.40	.88	1.50	.46	.78
No. 4 Screen to 3	Proportions	1	1.1	3.9	1	1.4	4.1	1	1.5	4.1	1	1.7	4.1	1	2.0	3.7
	Quantities	1.69	.28	.97	1.58	.33	.97	1.49	.33	.90	1.49	.37	.90	1.49	.44	.81
⅜ to ¾	Proportions	1	1.3	2.3	1	1.7	2.3	1	1.9	2.3	1	2.2	2.2	1	2.8	1.4
	Quantities	1.96	.37	.67	1.85	.46	.63	1.82	.51	.62	1.75	.57	.57	1.79	.75	.37
⅜ to 1	Proportions	1	1.3	2.6	1	1.7	2.6	1	1.9	2.5	1	2.2	2.4	1	2.7	1.7
	Quantities	1.90	.36	.74	1.77	.44	.68	1.72	.48	.64	1.67	.54	.59	1.72	.68	.43
⅜ to 1½	Proportions	1	1.3	3.0	1	1.7	3.0	1	1.9	3.0	1	2.1	2.9	1	2.6	2.2
	Quantities	1.82	.35	.80	1.68	.43	.75	1.63	.46	.73	1.61	.50	.68	1.62	.63	.53
⅜ to 2	Proportions	1	1.3	3.3	1	1.7	3.4	1	1.8	3.5	1	2.0	3.4	1	2.4	2.9
	Quantities	1.75	.34	.86	1.63	.41	.83	1.55	.42	.80	1.52	.45	.77	1.53	.62	.66
⅜ to 2½	Proportions	1	1.3	3.7	1	1.6	3.7	1	1.7	3.9	1	2.0	3.8	1	2.3	3.3
	Quantities	1.72	.33	.95	1.58	.37	.87	1.51	.37	.87	1.49	.44	.84	1.50	.51	.74
⅜ to 3	Proportions	1	1.2	3.8	1	1.6	3.9	1	1.7	4.0	1	1.9	4.0	1	2.2	3.5
	Quantities	1.68	.30	.95	1.58	.37	.91	1.49	.37	.88	1.49	.42	.88	1.49	.48	.77

TABLE XXX.—ABRAMS' TABLE OF PROPORTIONS AND QUANTITIES FOR 1 CU. YD. OF CONCRETE—*Continued*

Sizes		Fine aggregates, screen openings per inch														
Coarse aggregate, inches	Cement in barrels aggregates in cubic yards	0–28			0–14			0–8			0–4			0–¾ in.		
		Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse
½ to ¾	Proportions	1	1.5	2.3	1	1.9	2.2	1	2.1	2.2	1	2.3	2.1	1	2.8	1.3
	Quantities	1.96	.44	.67	1.85	.52	.61	1.82	.56	.59	1.75	.59	.54	1.79	.75	.34
½ to 1	Proportions	1	1.5	2.5	1	1.9	2.5	1	2.1	2.4	1	2.3	2.4	1	2.8	1.6
	Quantities	1.90	.42	.70	1.77	.50	.66	1.72	.53	.61	1.67	.57	.59	1.72	.72	.41
½ to 1½	Proportions	1	1.4	2.8	1	1.9	2.9	1	2.1	2.9	1	2.2	2.8	1	2.7	2.1
	Quantities	1.82	.37	.75	1.68	.47	.73	1.63	.51	.69	1.61	.52	.66	1.62	.65	.51
½ to 2	Proportions	1	1.4	3.3	1	1.9	3.3	1	2.0	3.4	1	2.2	3.3	1	2.7	2.7
	Quantities	1.75	.36	.86	1.63	.46	.79	1.55	.46	.78	1.52	.50	.74	1.53	.62	.62
½ to 2½	Proportions	1	1.4	3.6	1	1.8	3.6	1	1.9	3.7	1	2.1	3.7	1	2.6	3.1
	Quantities	1.72	.35	.91	1.58	.43	.85	1.51	.42	.83	1.49	.46	.81	1.50	.57	.69
½ to 3	Proportions	1	1.3	3.7	1	1.8	3.8	1	1.8	3.9	1	2.1	4.0	1	2.4	3.3
	Quantities	1.68	.33	.92	1.58	.42	.89	1.49	.40	.86	1.49	.46	.88	1.49	.53	.63
¾ to 1	Proportions	1	1.7	2.4	1	2.1	2.4	1	2.4	2.1	1	2.6	2.2	1	3.1	1.5
	Quantities	1.90	.48	.68	1.77	.55	.63	1.72	.61	.53	1.67	.64	.55	1.72	.79	.39
¾ to 1½	Proportions	1	1.7	2.7	1	2.0	2.8	1	2.3	2.7	1	2.5	2.7	1	3.0	2.0
	Quantities	1.82	.46	.73	1.79	.50	.70	1.63	.55	.65	1.61	.59	.64	1.62	.73	.48
¾ to 2	Proportions	1	1.7	3.1	1	2.0	3.1	1	2.3	3.1	1	2.5	3.0	1	3.0	2.4
	Quantities	1.75	.44	.80	1.63	.48	.75	1.55	.53	.72	1.52	.56	.67	1.53	.68	.55
¾ to 2½	Proportions	1	1.7	3.3	1	2.0	3.5	1	2.3	3.4	1	2.4	3.4	1	2.9	2.8
	Quantities	1.72	.43	.84	1.63	.47	.83	1.51	.52	.76	1.49	.53	.75	1.50	.64	.62
¾ to 3	Proportions	1	1.7	3.5	1	2.0	3.7	1	2.3	3.7	1	2.4	3.6	1	2.8	3.1
	Quantities	1.68	.43	.88	1.58	.47	.87	1.49	.51	.81	1.49	.53	.79	1.49	.62	.68
1 to 1½	Proportions	1	1.7	2.8	1	2.0	2.9	1	2.3	2.7	1	2.6	2.6	1	3.1	2.0
	Quantities	1.82	.46	.75	1.68	.50	.73	1.63	.55	.65	1.61	.62	.62	1.62	.75	.48
1 to 2	Proportions	1	1.5	3.2	1	1.9	3.5	1	2.2	3.3	1	2.4	3.3	1	3.0	2.6
	Quantities	1.75	.39	.83	1.63	.46	.85	1.58	.51	.76	1.52	.54	.74	1.53	.68	.59
1 to 2½	Proportions	1	1.4	3.4	1	1.9	3.8	1	2.0	3.7	1	2.3	3.7	1	2.7	3.1
	Quantities	1.72	.35	.86	1.58	.45	.89	1.51	.44	.83	.149	.51	.81	1.50	.59	.69
1 to 3	Proportions	1	1.3	3.6	1	1.8	4.0	1	2.0	3.9	1	2.2	3.9	1	2.7	3.3
	Quantities	1.67	.33	.90	1.58	.42	.94	1.49	.44	.86	1.49	.48	.86	1.49	.59	.73

TABLE XXXI.—A. S. T. M. STANDARD SIEVES

(To be used for asphalt pavement materials only)

(See A. S. T. M. Standard Method, Serial Designation D 7-27)

Mesh designation	Sieve opening in inches	Wire diameter in inches	Tolerance in average opening, per cent	Tolerance on wire diameter, per cent		Tolerance in maximum opening, per cent
				Under	Over	
10	0.0787	0.0299	±3	15	30	10
20	0.0331	0.0165	±5	15	30	25
30	0.0232	0.0130	±5	15	30	25
40	0.0165	0.0098	±5	15	30	25
50	0.0117	0.0074	±6	15	35	40
80	0.0070	0.0047	±6	15	35	40
100	0.0059	0.0040	±6	15	35	40
200	0.0029	0.0021	±8	15	35	60

For Concrete Aggregates.—A set of standard sieves for use in performing the sieve analysis of concrete aggregates; of broken stone for macadam construction, and of gravel for road surfacing, has also been adopted by the American Society for Testing Materials.[1] These are shown in Table XXXII and should always be used for the class of aggregates for which they are recommended.

[1] See A. S. T. M. Standard Method of Mechanical Analysis of Sand or Other Fine Highway Material, *Serial Designation* D 7, 27.

TABLE XXXII.—UNITED STATES STANDARD LABORATORY SIEVES

(Not used in analysis of asphalt pavement materials)

(See A. S. T. M. Standard Method, Serial Designation C 41-24)

Sieve number or size in inches	Sieve opening, inches	Wire diameter, inches	Tolerence, per cent			
			Average opening	Wire diameter		Maximum opening
				Under	Over	
No. 100	0.0059	0.0040	6	15	35	40
No. 50	0.0117	0.0074	6	15	35	40
No. 30	0.0232	0.0130	5	15	30	25
No. 16	0.0469	0.0213	3	15	30	10
No. 8	0.0937	0.0331	3	15	30	10
No. 4	0.187	0.050	3	15	30	10
⅜ in.	0.375	0.092	3	10	10	10
¾ in.	0.75	0.135	3	10	10	10
1 in.	1.00	0.162	3	10	10	10
1½ in.	1.50	0.177	3	10	10	10
2 in.	2.00	0.192	3	10	10	10
3 in.	3.00	0.25	3	10	10	10

Sieves No. 100 to No. 4 are based on "Table of Fundamental Data on Standard Specifications for Sieves" issued by the U. S. Bureau of Standards, 1920. The liberal tolerances will permit the use of certain sieves which do not exactly correspond to the number given in the table.

TABLE XXXIII.—STANDARD COMMERCIAL BROKEN STONE

Maximum Permissible Range in Sieve Analysis for Each Size
Percentage by Weight Passing Laboratory Screens
(A. S. T. M. Tentative Standard, Serial Designation D 63-23T)

Designated size, inches	Diameter of screen openings, inches						
	¼	½	¾	1	1¼	2½	3½
0 – ¼	85–100						
0 – ½	0–75	95–100					
0 – ¾	40–80	.....	95–100				
¼– ¾	0–15	25–75	95–100				
¼–1¼	0–5	.....	25–75	.....	95–100		
¼–2½	0–5	.....	.....	.....	25–75	95–100	
¾–1¼	.....	.....	0–15	25–75	95–100		
1¼–2½	.....	.....	.....	.....	0–15	95–100	
2½–3½[a]	.....	.....	.....	.....	.....	0–15	95–100

[a] In the case of light or porous slags a 4-in. maximum size may be specified instead of 3½ in.

TABLE XXXIV.—VARIOUS USES FOR WHICH THE DIFFERENT SIZES OF STONE ARE ADAPTED

(A. S. T. M. Tentative Standard, Serial Designation D 63-23T)

Designated size, inches	Suggested uses
0 – ¼	For fine screenings for water-bound macadam.
0 – ½	For fine aggregate for bituminous concrete.
¼– ¾	For dustless screenings or chips for bituminous macadam or bituminous surface treatment.
¾–1¼	For coarse chips or 1-in. stone for bituminous macadam.
1¼–2½	For wearing course waterbound macadam or bituminous macadam.
2½–3½	For broken-stone base course.
	Combination Sizes
0 – ¾	For coarse screenings for waterbound macadam.
¼–1¼	For aggregate for reinforced concrete, bituminous concrete, sheet asphalt binder course.
¼–2½	For coarse aggregate for cement-concrete roads and structures.

TABLE XXXV.—STANDARD COMMERCIAL GRAVEL

Maximum Permissible Range in Sieve Analysis for Each Size Percentage by Weight Passing Each Screen

(A. S. T. M. Tentative Standard, Serial Designation D 64-20T)

Designated size, inches	Diameter of screen openings, inches							
	¼	½	¾	1	1½	2	2½	3½
0 – ¼[a]	95–100							
0 – ¼[b]	85–100							
¼– ½	[c]	95–100						
¼– ¾	[c]	.....	95–100					
¼–1	[c]	25–75	.....	95–100				
¼–1½	[c]	.....	25–75	.....	95–100			
¼–2	[c]	.....	.....	25–75	.....	95–100		
¼–2½	[c]	.....	.....	.....	25–75	.....	95–100	
1 –2	.....	.....	.....	0–15	.....	85–100		
2 –3½	.....	.....	.....	.....	.....	0–15	.....	85–100

[a] Additional requirements for grading shall be as follows:

Passing 20-mesh sieve..... 25 to 75 per cent
Passing 50-mesh sieve..... not over 25 per cent
Passing 100-mesh sieve..... not over 5 per cent

[b] Limits for silt and clay content may be inserted if desired.

[c] Any percentage from 0 to 10 per cent may be designated, with a maximum permissible variation therefrom of not more than 2½ per cent

SIEVE ANALYSIS OF SAND OR FINE AGGREGATE

(A. S. T. M. Standard, Serial Designation D 7-27, slightly modified)

The method shall consist of (1) drying at not over 110°C. (230°F.) to a constant weight a sample weighing 50 g.; (2) passing the sample through each of the mesh sieves[1] (American Society for Testing Materials standard sieves) specified in Table XXXI; (3) determining the percentage by weight retained on each sieve, the sifting being continued on each sieve until less than 1 per cent of the weight retained on each sieve shall pass through the sieve during the last minute of sifting; and (4) recording the mechanical analysis in the following manner:

[1] The order in which the sieves are to be used in the process of sifting is immaterial and shall be left optional; but in reporting results the order in which the sieves have been used shall be stated.

	Per Cent
Passing 200-mesh sieve	
Passing 100-mesh sieve and retained on 200-mesh sieve	
Passing 80-mesh sieve and retained on a 100-mesh sieve	
Passing 50-mesh sieve and retained on an 80-mesh sieve	
	100.00

SIEVE ANALYSIS OF BROKEN STONE, GRAVEL, PEBBLES, OR BROKEN SLAG

(A. S. T. M. Standard Method D 18–16 slightly modified)

The method shall consist of (1) drying at not over 110°C. (230°F.) to a constant weight a sample weighing in pounds 6 times the diameter in inches of the largest holes required; (2) passing the sample through such of the following size screens having circular openings as are required or called for by the specifications, screens to be used in the order named 3½ in., 3 in., 2½ in., 2 in., 1½ in., 1¼ in., 1 in., ¾ in., ½ in., and ¼ in.; (3) determining the percentage by weight retained on each screen; and recording the mechanical analysis in the following manner:

	Per Cent
Passing ¼-in. screen	
Passing ½-in. screen and retained on ¼-in. screen	
Passing ¾-in. screen and retained on ½-in. screen	
Passing 1-in. screen and retained on ¾-in. screen	
	100.00

TESTS FOR DETERMINING THE AMOUNT OF CLAY AND SILT IN GRAVEL

The specification covers the determination of the quantity of clay and silt in natural gravel to be used in road construction.

The sample as received shall be moistened and thoroughly mixed, then dried to constant weight at a temperature between 100°C. (212°F.) and 110°C. (230°F.).

A representative portion of the dry material weighing not less than 50 times the weight of the largest stone in the sample, shall be selected from the sample, and placed in a dried and accurately weighed pan or vessel. The pan shall be 30.2 cm. (12 in.) in diameter by not less than 10.2 cm. (4 in.) deep, as nearly as may be obtained. Pour sufficient water in the pan to cover the gravel and agitate vigorously for fifteen (15) seconds, using a trowel or stirring rod. Allow to settle for fifteen (15) seconds, and then pour off the water into a tared evaporating dish, being careful not to pour off any sand. Repeat until the wash water is clear.

Dry the washed material to constant weight in an oven at between 100°C. (212°F.) and 110°C. (230°F.), weigh, and determine net weight of gravel.

Compute the percentage of clay and silt as follows:

$$\frac{\text{Original weight} - \text{weight after washing}}{\text{Original weight}} \times 100 = \text{percentage of clay and silt}$$

PROPOSED SOUNDNESS TEST FOR COARSE AGGREGATE

Immerse 10 small pieces of the rock in a saturated solution of sodium sulphate (Na_2SO_4) for 20 hr., after which place for 4 hr. in a drying oven maintained at 100°C. Repeat the treatment five times. The condition of the rock as to soundness is noted at the end of the test.

Samples which exhibit marked checking, cracking, or disintegration shall be considered to have failed in this test.

TEST FOR APPARENT SPECIFIC GRAVITY AND ABSORPTION OF STONE OR OTHER COARSE MATERIALS

The apparent specific gravity shall be obtained by weighing the water displaced by a sample of the material, weighing approximately 1,000 g., broken into pieces about 1¼ in. in diameter. It consists of a galvanized-iron cylinder closed at one end and measuring 5 in. in diameter by 8 in. high. A brass spout ½ in. in diameter is soldered into the side of the cylinder 6 in. from the bottom. The spout is inclined at an angle of 2 deg. with the horizontal and is 2½ in. long. A notch is filed across its lower end, as shown, to stop the drip from the displaced water. To determine the specific gravity, the dried and cooled sample shall be weighed to the nearest 0.5 g. and immersed in water for 24 hr. The pieces shall then be surface-dried individually with a towel, the sample reweighed and immediately placed in the cylinder, which has previously been filled to overflowing with water at room temperature.

The weight of water displaced by the sample shall be used to calculate its apparent specific gravity. The difference between the original weight of the sample and its weight after 24 hr. shall be used to determine the absorption.

ABRASION TEST FOR ROCK

The machine shall consist of one or more hollow iron cylinders, closed at one end and furnished with a tightly fitting iron cover at the other; the cylinders to be 20 cm. in diameter and 34 cm. in depth inside. These cylinders are to be mounted on a shaft at an angle of 30 deg. with the axis of rotation of the shaft.

The rock to be tested shall be prepared from sufficiently large-sized pieces to give as nearly a uniform size and shape, and as near to 50 pieces as possible shall constitute a sample. No pieces having edges or faces that have been rounded by wear shall be included. The total weight of rock in a test shall be within 10 g. of 5 kg. All test pieces shall be washed and thoroughly dried before weighing. Ten thousand revolutions, at the rate of between 30 and 33 per minute, shall constitute a test. Only the percentage

of material worn off which will pass through a 0.16 cm. ($\frac{1}{16}$ in.) mesh sieve shall be considered in determining the amount of wear. This shall be expressed as the percentage of the 5 kg. used in the test.

For materials having a specific gravity below 2.20 the quantity used for the test shall be adjusted on a volume basis, retaining the specified numbers and size of pieces. For such materials a volume of 4,000 g. of the broken stone or broken slag shall be used.

The results shall be reported as percentage of wear.

SLUMP TEST FOR CONSISTENCY OF CONCRETE

This test covers the method to be used both in the laboratory and in the field for determining consistency of concrete to be used for concrete pavements or for concrete base for pavements.

The test specimen shall be formed in a mold of No. 16-gage galvanized metal in the form of the lateral surface of the frustum of a cone with the base 8 in. in diameter, the upper surface 4 in. in diameter, and the altitude 12 in. The base and the top shall be open and parallel to each other and at right angles to the axis of the cone. The mold shall be provided with foot pieces and handles.

When the test is made at the mixer, the sample shall be taken from the pile of concrete after the entire batch has been discharged. For concrete that has been hauled from a central mixing plant, the sample shall be taken from the concrete after it has been dumped on the subgrade.

The mold shall be placed on a flat, non-absorbent surface such as a smooth plank or a slab of concrete, and the operator shall hold the mold firmly in place while it is being filled, by standing on the foot pieces. The mold shall be filled to about one-fourth of its height with the concrete which shall then be puddled, using 20 to 30 strokes of a $\frac{1}{2}$-in. rod, pointed at the lower end. The filling shall be completed in successive layers similar to the first and the top struck off so that the mold is exactly filled. The mold shall then be removed by being raised vertically and at exactly 3 min. after being filled. The molded concrete shall then be allowed to subside until quiescent and the height of the specimen measured.

The consistency shall be recorded in terms of inches of subsidence of the specimen during the test, which shall be known as the slump.

Slump = 12 in. − height after subsidence.

STANDARD METHODS OF TEST FOR APPARENT SPECIFIC GRAVITY OF SAND, STONE, AND SLAG SCREENINGS, AND OTHER FINE NON-BITUMINOUS HIGHWAY MATERIALS

(A. S. T. M. Standard, Serial Designation D 55–25)

The following tests, "Le Chatelier" and "Jackson," are equally suited for use in determining the apparent specific gravity of sand, stone, and slag screenings and other fine non-bituminous highway materials, and may be considered as alternates.

A. Le Chatelier Test

The determination of specific gravity shall be made with a Le Chatelier apparatus as standardized by the United States Bureau of Standards.

Kerosene or water, or benzine not lighter than 62°Bé., shall be used in making this determination.

The flask shall be filled with either of these liquids to a point on the stem between zero and 1 cc. and 50 to 64 g. of sand or other fine non-bituminous highway material of the same temperature as the liquid, shall be slowly introduced, taking care that the material does not adhere to the inside of the flask above the liquid, and to free the material from air by rolling the flask in an inclined position. After all material is introduced, the level of the liquid will rise to some division of the graduated neck; the difference between readings is the volume displaced by 64 g. of the material.

The specific gravity shall then be calculated from the formula:

$$\text{Specific gravity} = \frac{\text{Weight of material (g.)}}{\text{(Displaced volume cc.)}}$$

The flask, during the operation, shall be kept immersed in water, in order to avoid variations in the temperature of the liquid in the flask, which shall not exceed 0.5°C. The results of repeated tests should agree within 0.01.

B. Jackson Test

The determination shall be made with the Jackson specific gravity apparatus which shall consist of a burette, with graduations reading to 0.02 in specific gravity, about 28 cm. (11 in.) in length and with an inside diameter of about 0.7 cm. (0.3 in.), which shall be connected with a glass bulb approximately 13 cm. (5⅛ in.) in length and 4.5 cm. (1.75 in.) in diameter, the glass bulb being of such size that from a mark on the neck above the bulb to the top graduation on the burette, the capacity shall be such that the graduations shall read directly the specific gravity when 50 g. of materials are used; and an Erlenmeyer flask, which shall contain a hollow ground-glass stopper having a neck of approximately 6- to 8-mm. bore and which shall have a capacity of exactly 200 cc. (6.76 oz.) up to the graduation on the neck of the stopper.

(1) Dry at not more than 110°C. (230°F.) to a constant weight a sample weighing about 55 g.; (2) weigh 50 g. of the dry sample to 0.1 g. and pour it into the unstoppered Erlenmeyer flask, which shall be cleaned and dried before each determination; (3) fill the bulb and burette with kerosene, leaving just space enough to take the temperature by introducing a thermometer through the neck; (4) remove the thermometer and add sufficient kerosene to fill exactly to the mark on the neck, drawing off any excess with the burette; (5) run into the flask about one-half of the kerosene in the bulb to remove air bubbles and then run in more kerosene, removing any material adhering to the neck of the flask, until the kerosene is just below the ground glass; (6) place the hollow ground-glass stopper in position and turn it to fit tightly, and then run in kerosene exactly to the 200-cc. (6.76 oz.) graduation on the neck, care being taken to remove all air bubbles in the flask; (7) read the specific gravity from the graduation on the burette, and the temperature of the oil in the flask, noting the difference between the temperature of the oil in the bulb before the determination and that of the oil in the flask after the determination; (8) make a temperature correction to the reading of the specific gravity in accordance with the table furnished by the manufacturer

of the apparatus, adding the correction if the temperature of the kerosene has increased, and subtracting it if the temperature of the kerosene has decreased.

STANDARD METHODS OF TEST FOR TOUGHNESS OF ROCK

(A. S. T. M. Standard, Serial Designation D 3–18)

Toughness, as applied to rock, is the resistance offered to fracture under impact, expressed as the final height of blow required of a standard hammer to cause fracture of a cylindrical test specimen of given dimensions.

Any form of impact machine which will comply with the following essentials may be used in making the test:

(*a*) A cast-iron anvil weighing not less than 50 kg. firmly fixed upon a solid foundation.

(*b*) A hammer weighing 2 kg. arranged so as to fall freely between suitable guides.

(*c*) A plunger made of hardened steel and weighing 1 kg., arranged to slide freely in a vertical direction in a sleeve, the lower end of the plunger being spherical in shape with a radius of 1 cm.

(*d*) Means for raising the hammer and for dropping it upon the plunger from any specified height from 1 to not less than 75 cm., and means for determining the height of fall to approximately 1 mm.

(*e*) Means for holding the cylindrical test specimen securely on the anvil without rigid lateral support, and under the plunger in such a way that the center of its upper surface shall, throughout the test, be tangent to the spherical end of the plunger at its lowest point.

Quarry samples of rock from which test specimens are to be prepared shall measure at least 6 in. on a side and at least 4 in. in thickness, and when possible shall have the plane of structural weakness of the rock plainly marked thereon. Samples should be taken from freshly quarried material, and only from pieces which show no evidences of incipient fracture due to blasting or other causes. The samples should preferably be split from large pieces by the use of plugs and feathers and not by sledging. Commercial stone-block samples from which test specimens are to be prepared shall measure at least 3 in. on each side.

Specimens for test shall be cylinders prepared as described in Sec. 5, 25 mm. in height and from 24 to 25 mm. in diameter. Three test specimens shall constitute a test set. The ends of the specimen shall be plane surfaces at right angles to the axis of the cylinder.

One set of specimens shall be drilled perpendicular and another parallel to the plane of structural weakness of the rock, if such plane is apparent. If a plane of structural weakness is not apparent, one set of specimens shall be drilled at random. Specimens shall be drilled in a manner which will not subject the material to undue stresses and which will insure the specified dimensions. The ends of the cylinders may be sawed by means of a band or diamond saw, or in any way which will not induce incipient fracture, but shall not be chipped or broken off with a hammer. After sawing, the ends of the specimens shall be ground plane with water and carborundum or emery on a cast-iron lap until the cylinders are 25 mm. in length.

Test shall consist of a 1-cm. fall of the hammer for the first blow, a 2-cm. fall for the second blow, and an increase of 1-cm. fall for each succeeding blow until failure of the test specimen occurs.

The height of the blow in centimeters at failure shall be the toughness of the test specimen. The individual and the average toughness of three test specimens shall be reported when no plane of structural weakness is apparent. In cases where a plane of structural weakness is apparent, the individual and average toughness of the three specimens in each set shall be reported and identified. Any peculiar condition of a test specimen which might affect the result, such as the presence of seams, fissures, etc., shall be noted and recorded with the test result.

ABRASION TEST FOR GRAVEL

The aggregate shall first be screened through screens having circular openings 2 in., 1½ in., 1 in., ¾ in., and ½ in. in diameter. The material of these sizes shall be washed and dried. The following weights of the dried stone shall then be taken: 1,250 g. of the size passing the 2-in. and retained on the 1½-in. screen, 1,250 g. of the size passing the 1½-in. and retained on the 1-in. screen, 1,250 g. passing the 1-in. screen and retained on the ¾-in. screen, 1,250 g. passing the ¾-in. screen and retained on the ½-in. screen. This material shall be placed in the cast-iron cylinder of the Deval machine as specified for the standard abrasion test on stone. Six cast-iron spheres 1.875 in. in diameter and weighing approximately 0.95 lb. (0.45 kg.) each, shall be placed in the cylinder as an abrasive charge. These spheres are the same as those used in the standard rattler test for paving brick.

The duration of the test and the rate of rotation shall be the same as specified for the standard test for stone, namely, 10,000 revolutions at the rate of 30 to 33 r. p. m. At the completion of the test the material shall be taken out and screened over a $\frac{1}{16}$-in. mesh sieve. The material retained upon the sieve shall be washed and dried and the percentage loss by abrasion of the material passing the $\frac{1}{16}$-in. mesh sieve calculated.

When the material has a specific gravity below 2.20 a total weight of 4,000 gm. made up of the four groups of sizes described above, instead of 5,000 gm., shall be used in the abrasion test.

TENTATIVE METHOD OF TEST FOR ORGANIC IMPURITIES IN SANDS FOR CONCRETE

(A. S. T. M. Standard, Serial Designation C 40–27)

The test herein specified is an approximate test for the presence of injurious organic compounds in natural sands for cement mortar or concrete. The principal value of the test is in furnishing a warning that further tests of the sand are necessary before they be used in concrete.

(*a*) A representative test sample of sand of about 1 lb. shall be obtained by quartering or by the use of a sampler.

(*b*) A 12-oz. graduated glass prescription bottle shall be filled to the 4½-oz. mark with the sand to be tested.

(*c*) A 3-per cent solution of sodium hydroxide (NaOH) in water shall be added until the volume of sand and liquid after shaking gives a total volume of 7 liquid ounces.

(*d*) The bottle shall be stoppered and shaken thoroughly and then allowed to stand for 24 hr.

(*e*) A standard color solution shall be prepared by adding 2.5 cc. of a 2-per cent solution of tannic acid in 10-per cent alcohol to 97.5 cc. of a 3-per cent sodium-hydroxide solution. This shall be placed in a 12-oz. prescription bottle, stoppered, and allowed to stand for 24 hr.

(*f*) After standing 24 hr., the color of the clear liquid above the sand shall be compared with the color of the standard color solution prepared at the same time and in accordance with the method described in Sec. 4, or with a glass of color similar to the color of the standard solution.

Solutions darker in color than the standard color have a "color value" higher than 250 parts per million in terms of tannic acid.

TESTS OF VITRIFIED PAVING BRICK

(A. S. T. M. Standard Method, Serial Designation, C 7–15)

Tests of Paving Brick.—The quality and acceptability of paving brick, in the absence of other special tests mutually agreed upon in advance by the seller on the one side and the buyer on the other side, shall be determined by the following procedure:

I. The rattler test, for the purpose of determining whether the material as a whole possesses to a sufficient degree strength, toughness, and hardness.

II. Visual inspection, for the purpose of determining whether the physical properties of the material as to dimensions, accuracy, and uniformity of shape and color, are in general satisfactory, and for the purpose of culling out from the shipment individually imperfect or unsatisfactory brick.

The acceptance of paving brick as satisfactorily meeting one of these tests shall not be construed as in any way waiving the other.

I. THE RATTLER TEST

The Selection of Samples for Testing

1. Place of Sampling.—In general, where a shipment of bricks involving a quantity of less than 100,000 is under consideration, the sampling may be done either at the brick factory prior to shipment, or on cars at their destination or on the street when delivered ready for use.

The iron composing these spheres shall have a chemical composition within the following limits:

Composition of Standard Brick Rattler Shot

	Per Cent
Combined carbon	Not under 2.50
Graphitic carbon	Not over 0.25
Silicon	Not over 1.00
Manganese	Not over 0.50
Phosphorus	Not over 0.25
Sulfur	Not over 0.08

For each new batch of spheres used, the chemical analysis shall be furnished by the maker or be obtained by the user, before introducing into the

charge, and unless the analysis meets the above specifications, the batch of spheres shall be rejected.

THE OPERATION OF THE TEST

* * * * * *

10. The Brick Charge.—The number of bricks per test shall be ten for all bricks of so-called "block-size," whose dimensions fall between 8 and 9 in. in length, 3 and 3¾ in. in width, and 3¾ and 4¼ in. in thickness. No brick should be selected as part of a regular test that would be rejected by any other requirements of the specifications under which the purchase is made.

11. Speed and Duration of Revolution.—The rattler shall be rotated at a uniform rate of not less than 29.5 nor more than 30.5 r. p. m. and 1,800 revolutions shall constitute the test. A counting machine shall be attached to the rattler for counting the revolutions. A margin of not to exceed 10 revolutions will be allowed for stopping. Only one start and stop per test is generally acceptable. If, from accidental causes, the rattler is stopped and started more than once during a test, and the loss exceeds the maximum permissible under the specifications, the test shall be disqualified and another made.

12. The Scales.—The scales must have a capacity of not less than 300 lb., and must be sensitive to 0.5 oz., and must be tested by a standard test weight at intervals of not less than every ten tests.

13. The Results.—The loss shall be calculated in percentage of the initial weight of the brick composing the charge. In weighing the rattled brick, any piece weighing less than 1 lb. shall be rejected.

14. The Records.—A complete and continuous record shall be kept of the operation of all rattlers working under these specifications. This record shall contain the following data concerning each test made:

1. The name of the person, firm, or corporation furnishing each sample tested.
2. The name of the maker of the brick represented in each sample tested.
3. The name of the street or contract which the sample represented.
4. The brands or marks upon the bricks by which they were identified.
5. The number of bricks furnished.
6. The date on which they were received for test.
7. The date on which they were tested.
8. The drying treatment given before testing, if any.
9. The length, breadth, and thickness of the bricks.
10. The collective weight of the ten large spherical shot used in making the test at the time of their last standardization.
11. The number and collective weight of the small spherical shot used in making the test, at the time of their last standardization.
12. The total weight of the shot charge, after its last standardization.
13. Certificate of the operator that he examined the condition of the machine as to staves, liners, and any other parts affecting the barrel, and found them right at the beginning of the test.
14. Certificate of the operator of the number of charges tested since the last standardization of shot charge and last renewals of stave-liners.

15. The time of the beginning and ending of each test, and the number of revolutions made by the barrel during the test, as shown by the indicator.

16. Certificate of the operator as to number of stops and starts made in each test.

17. The initial collective weight of the ten bricks composing the charge and their collective weight after rattling.

18. The loss calculated in percentage of the initial weight; and the calculation itself.

19. The number of broken bricks and remarks upon the portions which were included in the final weighing.

20. General remarks upon the test and any irregularities occurring in its execution.

21. Date on which the test was made.

22. The name of the owner and location of the rattler, upon which the test was made.

23. The certificate of the operator that the test was made under the specifications of the American Society for Testing Materials and that the record is a true record.

24. The signature of the operator or person responsible for the test.

25. The serial number of the test.

In the event of more than one copy of the record of any test being required they may be furnished on separate sheets, and marked duplicates, but the original record shall always be preserved intact and complete.

For the convenience of the public, the accompanying blank form which provides space for the necessary data, is furnished and its use recommended.

ACCEPTANCE AND REJECTION OF MATERIAL

15. Basis of Acceptance or Rejection.—Paving bricks shall not be judged for acceptance or rejection by the results of individual tests; but by the average of no less than five tests. Where a lot of bricks fail to meet the required average, it shall be optional with the buyer whether the bricks shall be definitely rejected or whether they may be regraded and a portion selected for further test as provided in Sec. 16.

16. Range of Fluctuation.—Some fluctuation in the results of the rattler test, both on account of variations in the bricks and in the machine used in testing, are unavoidable, and a reasonable allowance for such fluctuations should be made wherever the standard may be fixed.

In any lot of paving brick, if the loss on a test computed upon its initial weight exceeds the standard loss by more than 2 per cent, then the portion of the lot represented by that test shall at once be resampled and three more tests executed upon it, and if any of these three tests shall again exceed by more than 2 per cent the required standard, then that portion of the lot shall be rejected.

If in any lot of brick two or more tests exceed the permissible maximum, then the buyer may at his option reject the entire lot, even though the average of all the tests executed may be within the required limits.

17. Fixing of Standards.—The percentage of loss which may be taken as the standard will not be fixed in these specifications, and shall remain within the province of the contracting parties. For the information of the

public, the following scale of average losses is given, representing what may be expected of tests executed under the foregoing specifications:

Rattler Loss Specifications

	General Average Loss, Per Cent	Maximum Permissible Loss, Per Cent
For bricks suitable for heavy traffic..	22	24
For bricks suitable for medium traffic	24	26
For bricks suitable for light traffic ..	26	28

Which of these grades should be specified in any given district and for any given purpose is a matter wholly within the province of the buyer, and should be governed by the kind and amount of traffic to be carried and the quality of paving bricks available.

18. Culling and Retesting.—Where, under Secs. 15 and 16 a lot or portion of a lot of bricks is rejected, either by reason of failure to show a low enough average test or because of tests above the permissible maximum, the buyer may at his option permit the seller to regrade the rejected brick, separating out that portion which he considers at fault and retaining that which he considers good. When the regrading is complete, the good portion shall be then resampled and retested, under the original conditions, and if it fails again either in average or in permissible maximum, then the buyer may definitely and finally reject the entire lot or portion under test.

19. Payment of Cost of Testing.—Unless otherwise specified, the cost of testing the material as delivered or prepared for delivery, up to the prescribed number of tests for valid acceptance or rejection of the lot, shall be paid by the buyer (see also Sec. 23). The cost of testing extra samples made necessary by the failure of the whole lot or any portion of it shall be paid by the seller whether the material is finally accepted or rejected.

II. Visual Inspection

It shall be the right of the buyer to inspect the bricks, subsequent to their delivery at the place of use, and prior to or during laying, to cull out and reject upon the following grounds:

20. All bricks which are broken in two or chipped in such a manner that neither wearing surface remains substantially intact, or that the lower or bearing surface is reduced in area by more than one-fifth. Where bricks are rejected upon this ground it shall be the duty of the purchaser to use them so far as practicable in obtaining the necessary half-bricks for breaking courses and making closures, instead of breaking otherwise whole and sound bricks for this purpose.

21. All bricks which are cracked in such a degree as to produce defects such as are defined in Sec. 20, either from shocks received in shipment and handling, or from defective conditions of manufacture, especially in drying, burning, or cooling, unless such cracks are plainly superficial and not such as to perceptibly weaken the resistance of the brick to its conditions of use.

22. All bricks which are so off size, or so misshapen, bent, twisted, or kiln-marked that they will not form a proper surface as defined by the paving specifications, or align with other bricks without making joints other than those permitted in the paving specifications.

23. All bricks which are obviously too soft and too poorly vitrified to endure street wear. When any disagreement arises between buyer and seller under this item, it shall be the right of the buyer to make two or more rattler tests of the brick which he wishes to exclude, as provided in Section 2, and if in either or both tests the bricks fall beyond the maximum rattler losses permitted under the specifications, then all bricks having the same objectionable appearance may be excluded and the seller shall pay for the cost of the test. But if, under such procedure, the bricks which have been tested as objectionable shall pass the rattler test, both tests falling within the permitted maximum, then the buyer cannot exclude the class of material represented by this test and he shall pay for the cost of the test.

24. All bricks which differ so markedly in color from the type or average of the shipment, as to make the resultant pavement checkered or disagreeably mottled in appearance. This section shall not be held to apply to the normal variations in color which may occur in the product of one plant among bricks which will meet the rattler test as referred to in Secs. 15, 16, and 17, but shall apply only to differences of color which imply differences in the material of which the bricks are made, or extreme differences in manufacture.

DUCTILITY OF BITUMINOUS MATERIALS

(A. S. T. M. Tentative Standard, Serial Designation D 113–26T)

The ductility of an asphalt cement or semi-solid bitumen is the distance to which it will elongate before breaking when two ends of a briquette of the material are pulled apart at a specified rate of speed and at a specified temperature. When the conditions of the test are not specifically mentioned, the rate and temperature are understood to be 5 cm. per minute at 25°C. (77°F.).

The dimensions of the mold shall be as follows:

Total length (internal)	7.45–7.55 cm.
Distance between clips	2.97–3.06 cm.
Width of clips at mouth	1.98–2.02 cm.
Width of briquette at minimum cross-section (half way between clips)	0.99–1.01 cm.
Thickness of briquette throughout	0.99–1.01 cm.

The water bath shall be maintained at a temperature not varying more than 0.1°C. from 25°C. (77°F.). The volume of water shall be not less than 10 liters and the sample shall be immersed to a depth of not less than 10 cm. and shall be supported on a perforated shelf not less than 5 cm. from the bottom of the bath.

Any apparatus may be used for pulling the briquette of bitumen apart, that is so constructed that the briquette will be continuously immersed in water and the two clips pulled apart at a uniform rate of speed of 5 cm. per minute.

The asphalt cement or bituminous material to be tested shall be completely melted at such a temperature that it will be thoroughly fluid—with ordinary paving asphalt cement this is about 160°C. (320°F.) It shall then

be strained through a 50-mesh sieve, and after a thorough stirring, poured into the mold. The mold shall be assembled on a brass plate. To prevent the material under test from sticking, the surface of the plate and the interior surfaces of the side pieces of the mold shall be thoroughly amalgamated. In filling the mold care shall be taken not to disarrange the parts and thus distort the briquette. In filling, the material shall be poured in a thin stream back and forth from end to end of the mold until it is more than level full. It shall be left to cool to room temperature and then placed in water maintained at 25°C. (77°F.) for 30 min., after which the excess of bitumen shall be cut off by means of a hot putty knife or spatula so that the mold shall be just level full.

The brass plate and mold, with briquette, shall then be placed in the water bath and kept at a temperature of 25°C. (77°F.) for at least 1½ hr., when briquette shall be removed from the plate and the side pieces detached.

The rings at each end of the clip shall then be attached to the pins or hooks in the ductility machine and the two clips pulled apart at a uniform rate of 5 cm. per minute (±5 per cent).

The distance through which the clips have been pulled to produce rupture shall then be measured in centimeters. While the test is being made, the water in the tank of the ductility machine shall cover the sample by at least 2.5 cm. and shall be kept continuously at a temperature within 0.5°C. of 25°C. (77°F.).

A normal test is one in which the material between the two clips pulls out to a point or thread until rupture occurs at the point where the thread has practically no cross-sectional area. The average of three normal tests shall be taken and reported as the ductility of the sample.

If a normal test is not obtainable on three successive tests, the ductility should be reported as being unobtainable under the conditions of the test.

FLOAT TEST FOR BITUMINOUS MATERIALS

(A. S. T. M. Standard Method, Serial Designation: D 139–27)

Apparatus

1. The float shall be made of aluminum or aluminum alloy and shall be in accordance with the following requirements:

	Minimum	Normal	Maximum
Weight of float, gram	37.70	37.90	38.10
Total height of float, millimeter	34.0	35.0	36.0
Height of rim above lower side of shoulder, millimeter	26.5	27.0	27.5
Thickness of shoulder, millimeter	1.3	1.4	1.5
Diameter of opening, millimeter	11.0	11.1	11.2

2. The collar shall be made of brass and shall be in accordance with the following requirements:

	Minimum	Normal	Maximum
Weight of collar, gram	9.60	9.80	10.00
Over-all height of collar, millimeter	22.3	22.5	22.7
Inside diameter at bottom, millimeter	12.72	12.82	12.92
Inside diameter at top, millimeter	9.65	9.70	9.75

The top of the collar shall screw up tightly against the lower side of the shoulder.

3. The assembled float and collar, with the collar filled flush with the bottom and weighted to a total weight of 53.2 g., shall float upon water with the rim 8.5 ± 1.5 mm. above the surface of the water.

4. The thermometer shall conform to the following requirements. These specifications cover a special thermometer graduated in either Centigrade or Fahrenheit degrees as specified, the ranges being −2 to +80°C. or +30 to +180°F., respectively:

Type: Etched stem, glass.

Liquid: Mercury.

Range and subdivision: −2 to +80°C. in 0.2°C. or +30 to +180°F. in 0.5°F.

Total length: 378 to 384 mm. (14.88 to 15.12 in.).

Stem: Plain front, enamel back, suitable thermometer tubing. Diameter, 6.0 to 7.0 mm. (0.24 to 0.28 in.).

Bulb: Corning normal or equally suitable thermometric glass.
Length, 9 to 14 mm. (0.35 to 0.55 in.).
Diameter, 4.5 to 5.5. mm. (0.13 to 0.22 in.).

Diameter to 0°C. or 32°F. line from bottom of bulb: 75 to 90 mm. (2.95 to 3.54 in.).

Distance to 80°C. or 176°F. line from top of thermometer: 30 to 45 mm. (1.18 to 1.77 in.).

Expansion chamber: To permit heating the thermometer at least 50°C. (90°F.) above highest temperature on scale.

Filling above mercury: Nitrogen gas.

Top finish: Glass ring.

Graduation: All lines, figures, and letters clear cut and distinct. Each whole degree Centigrade or Fahrenheit line to be longer than the remaining lines. Graduations to be numbered at each multiple of 2°C. or 5°F.

Immersion: Total.

Special marking: "A. S. T. M. Low S.P.," a serial number and the manufacturer's name or trade mark shall be etched on the thermometer.

Scale error: The error at any point of the scale when the thermometer is standardized as provided below shall not exceed 0.2°C. or 0.4°F.

Standardization: The thermometer shall be standardized immersed in the testing bath to the top of the mercury column, at the ice point and at temperature intervals of approximately 20°C. or 40°F.

Case: The thermometer shall be supplied in a suitable case on which shall appear the marking: "A. S. T. M. Low S.P., −2 to +80°C." or "A. S. T. M. Low S.P", +30 to + 180°F. "according to the type of thermometer.

NOTE.—For the purpose of interpreting these specifications the following definitions apply:

The total length is the over-all length of the finished instrument.

The diameter is that measured with a ring gage.

The length of the bulb is the distance from the bottom of the bulb to the beginning of the enamel backing.

The top of the thermometer is the top of the finished instrument.

5. The diameter of the bath and the depth of water shall be at least 185 mm.

PREPARATION OF SAMPLE

6. The brass collar shall be placed with the smaller end on a brass plate which has been previously amalgamated with mercury by first rubbing it with a dilute solution of mercuric chloride or nitrate, and then with mercury.

The sample shall be completely melted at the lowest possible temperature that will bring it to a sufficiently fluid condition for pouring, excepting creosote oil residues, which shall be mixed and poured at a temperature of 100 to 125°C. It shall be stirred thoroughly until it is homogeneous and free from air bubbles. The sample shall then be poured into the collar in any convenient manner until slightly more than level with the top.

Asphalt and Asphalt Products.—Asphalt and asphalt products shall be cooled to room temperature, placed in water maintained at 5°C. for 5 min., after which the surplus material shall be removed by means of a spatula, or steel knife, which has been slightly heated. The collar and plate shall then be placed in a tin cup containing ice water maintained at 5°C., ±1°C., and left in this bath for at least 15 min.

Tar Products.—Tar products shall be immediately immersed in ice water maintained at 5°C. for 5 min., after which the surplus material shall be removed by means of a spatula or steel knife, which has been slightly heated. The collar and plate shall then be placed in a tin cup containing ice water maintained at 5°C., ±1°C., and left in this bath for at least 15 min.

PROCEDURE

7. (*a*) The bath shall be filled with water and the water heated to the temperature at which the test is to be made. This temperature shall be accurately maintained and shall at no time throughout the test be allowed to vary more than 0.5°C. from the temperature specified.

(*b*) After the material to be tested has been kept in the ice water for not less than 15 min. nor more than 30 min., the collar with its contents shall be removed from the plate and screwed into the aluminum float and immersed in water at 5°C. for 1 min. Any water shall then be removed from the inside of the float and the latter immediately floated in the warm bath. As the plug of material becomes warm and fluid, it is forced upward and out of the collar until the water gains entrance into the saucer and causes it to sink.

(*c*) The time in seconds between placing the apparatus on the water and when the water breaks through the material shall be determined by means of a stop watch, and shall be taken as a measure of the consistency of the material under examination.

NOTE.—Special precaution should be taken to insure the collar fitting tightly into the float and to see that there is no seepage of water between the collar and float during the test.

FLASH AND FIRE POINTS BY MEANS OF OPEN CUP

(A. S. T. M. Standard Serial Designation: D 92–24)

1. The open-cup flash and fire test on all products except fuel oils and those having an open-cup flash below 175°F. shall be determined in the Cleveland Open Cup.

APPARATUS

2. The cup shall be supported by a metal plate ¼-in. (0.635 cm.) in thickness and 6 in. (15.24 cm.) in width. The plate shall be of brass, cast iron, wrought iron, or steel. In the center of the plate there shall be a plane depression $\frac{1}{32}$-in. (0.079 cm.) in depth, and of just sufficient diameter to fit the cup. There shall be a circular opening $2\frac{3}{16}$ in. (5.50 cm.) in diameter, cut through the plate, centering with the center of the above-mentioned depression. The plate shall be covered with a sheet of hard asbestos board ¼-in. in thickness, and of the same shape as the metal plate. There shall be cut in the center of the asbestos board a circular hole just fitting the cup. Heat may be supplied from any convenient source. The use of a gas burner, electric heater, or alcohol lamp is permitted, but under no circumstances are products of combustion or free flame allowed to come up around the cup. The source of heat shall be centered under the opening in the plate and shall be of a type that will not produce local superheating. If a flame heater is used, it may be protected from drafts or excessive radiation by any suitable type of shield that does not project above the level of the upper surface of the asbestos board.

3. The thermometer shall conform to the following requirements. These specifications cover a special thermometer graduated in either Centigrade or Fahrenheit degrees as specified, the ranges being −6 to +400°C., or +20 to +760°F., respectively.

Type: Etched stem, glass.

Liquid: Mercury.

Range and subdivision: −6 to +400°C. in 2°C. or +20 to +760°F. in 5°F.

Total length: 303 to 307 mm. (11.92 to 12.08 in.)

Stem: Plain front, enamel back, suitable thermometer tubing.
Diameter, 6.0 to 7.0 mm. (0.24 to 0.28 in.)

Bulb: Corning normal or equally suitable thermometric glass.
Length, not over 13 mm. (0.51 in.).
Diameter, not greater than stem.

Distance to −6°C. or 20°F. line from bottom of bulb: 40 to 50 mm. (1.57 to 1.97 in.).

Filling above mercury: Nitrogen gas.

Top finish: Red glass ring.

Graduation: All lines, figures, and letters clear cut and distinct. The first and each succeeding 10°F. line to be longer than the intermediate lines. Graduations to be numbered at each multiple of 20°.

Immersion: 25 mm. or 1 in. The words "1-in. immersion" on Fahrenheit thermometers or "25 mm. immersion" on Centigrade thermometers and a line around the stem 25.4 mm. or 1.00 in. above the bottom of the bulb shall be etched on the thermometer.

Special marking: "A. S. T. M. Open Flash" a serial number and the manufacturer's name or trade mark shall be etched on the stem.

Scale error: The error at any point of the scale when the thermometer is standardized as provided below shall not exceed 1°C. up to 372°C. or 2½°F. up to 700°F.

Standardization: The thermometer shall be standardized at the ice point and at intervals of approximately 100°F. for 25 mm. or 1-in. immersion and for the following temperatures of the emergent mercury column:

Thermometer Reading		Average Temperature of Emergent Mercury Column	
100°C.	200°F.	44°C.	110°F.
150°C.	300°F.	54°C.	129°F.
200°C.	400°F.	64°C.	150°F.
250°C.	500°F.	77°C.	175°F.
300°C.	600°F.	91°C.	205°F.
350°C.	700°F.	108°C.	240°F.

Test for permanency of range: After being subjected to a temperature between 360 to 370°C. or 680 to 700°F. for 24 hr., the accuracy shall be within the limit specified.

Case: The thermometer shall be supplied in a suitable case on which shall appear the marking: "A. S. T. M. Open Flash, −6 to +400°C." or "A. S. T. M. Open Flash, +20 to +760°F.," according to the type of thermometer.

Note.—For the purpose of interpreting these specifications the following definitions apply.

The total length is the over-all length of the finished instrument.

The diameter is that measured with a ring gage.

The length of the bulb is the distance from the bottom of the bulb to the beginning of the enamel backing.

The top of the thermometer is the top of the finished instrument.

Procedure

4. (*a*) The thermometer shall be suspended or held in a vertical position by any suitable device. The bottom of the bulb shall be ¼ in. (0.635 cm.) from the bottom of the cup, and above a point half-way between the center and back of the cup.

(*b*) The cup shall be filled with the oil to be tested in such a manner that the top of the meniscus is exactly at the filling line at room temperature. The surface of the oil shall be free from bubbles. There shall be no oil above the filling line or on the outside of the apparatus.

(*c*) The test flame shall be approximately $\frac{5}{32}$-in (0.397 cm.) in diameter.

NOTE.—For purposes of comparison it is recommended that a bead of suitable light colored material be mounted in a convenient position so that the size of the test flame can be determined. The device for applying the flame may be of any suitable type but it is suggested that the tip be approximately $\frac{1}{16}$-in. (0.159 cm.) in diameter at the end and that the orifice be $\frac{1}{32}$-in. (0.079) cm. in diameter. If the device for operating the test flame be mounted in such a manner as to permit automatic duplication of the sweep of the test flame the radius of swing shall be not less than 6 in.

(*d*) The test flame shall be applied as the temperature read on the thermometer reaches each successive 5°F. mark. The flame shall pass in a straight line (or on the circumference of a circle having a radius of at least 6 in.) across the center of the cup and at right angles to the diameter passing through the thermometer. The test flame shall, while passing across the surface of the oil, be in the plane of the upper edge of the cup. The time for the passage of the test flame across the cup shall be approximately one second.

(*e*) The oil shall be heated at a rate not exceeding 30°F. per minute temperature rise, till a point is reached approximately 100°F. below the probable flash point of the oil. Thereafter the rate of heating shall be decreased and for at least the last 50°F. before the flash point is reached, the rate shall be not less than 9 nor more than 11°F. per minute.

5. The flash point shall be taken as the temperature read on the thermometer when a flash appears at any point on the surface of the oil. The true flash must not be confused with a bluish halo that sometimes surrounds the test flame.

6. After determining the flash point, the heating shall be continued at the specified rate of 9 to 11°F. per minute, and application of the test flame shall be made at the specified intervals until the oil ignites and continues to burn for a period of at least 5 sec. The method of application to the flame shall be the same or for flash point. The temperature read at the time of the flame application which causes burning for a period of 5 sec. or more shall be recorded as the fire point.

7. The flash-point and fire-point tests shall be made in a room or compartment free from air drafts. The operator shall avoid breathing over the surface of the oil. It is desirable that the room or compartment be darkened sufficiently so that the flash may be readily discernible.

PENETRATION OF BITUMINOUS MATERIALS

(A. S. T. M. Standard Method, Serial Designation D 5, 25)

Penetration is defined as the consistency of a bituminous material, expressed as the distance that a standard needle vertically penetrates a sample of the material under known conditions of loading, time, and temperature. Where the conditions of test are not specifically mentioned, the load, time, and temperature are understood to be 100 g., 5 sec., 25°C (77°F.) respectively, and the units of penetration to indicate hundredths of a centimeter.

The container for holding the material to be tested shall be a flat-bottom cylindrical dish, 55 mm. ($2\frac{3}{16}$ in.) in diameter and 35 mm. ($1\frac{3}{8}$ in.) deep.

The needle shall be a cylindrical steel rod 50.8 mm. (2 in.) long, having a diameter of 1.00 to 1.02 mm.

This shall be symmetrically tapered at one end to a cone approximately 6.35 mm. (¼-in.) in height and whose angle shall be within the range of 8°-40′ and 9°-40′.

After tapering, the point shall be "blunted" by grinding off to a truncated cone, the smaller base of which shall be from 0.14 to 0.16 mm. in diameter.[1] The finished needle shall be highly polished.

The water bath shall be maintained at a temperature not varying more than 0.1°C. from 25°C. (77°F). The volume of water shall be not less than 10.1 and the sample shall be immersed to a depth of not less than 10 cm. (4 in.) and shall be supported on a perforated shelf not less than 5 cm. (2 in.) from the bottom of the bath.

Any apparatus which will allow the needle to penetrate without appreciable friction, and which is accurately calibrated to yield results in accordance with the definition of penetration, will be acceptable.

The transfer dish for container shall be a small dish or tray of such capacity as will insure complete immersion of the container during the test. it shall be provided with some means which will insure a firm bearing and prevent rocking of the container.

The sample shall be completely melted at the lowest possible temperature and stirred thoroughly until it is homogeneous and free from air bubbles. It shall then be poured into the sample container to a depth of not less than 15 mm. (⅝ in.). The sample shall be protected from dust and allowed to cool in an atmosphere not lower than 18°C. (65°F.) for 1 hr. It shall then be placed in the water bath along with the transfer dish and allowed to remain 1 hr.

In making the test the sample shall be placed in the transfer dish filled with water from the water bath, of sufficient depth to completely cover the container. The transfer dish containing the sample shall be placed upon the stand of the penetration machine. The needle loaded with specified weight shall be adjusted to make contact with the surface of the sample. This may be accomplished by making contact of the actual needle point with its image reflected by the surface of the sample from a properly placed source of light. Either the reading of the dial shall then be noted or the needle brought to zero. The needle is then released for the specified period of time, after which the penetration machine is adjusted to measure the distance penetrated.

At least three tests shall be made at points on the surface of the sample not less than 1 cm. (⅜ in.) from the side of the container and not less than 1 cm. (⅜ in.) apart. After each test the sample and transfer dish shall be returned to the water bath and the needle shall be carefully wiped toward its point with a clean, dry cloth to remove all adhering bitumen. The reported penetration shall be the average of at least three tests whose values shall not differ more than four points between maximum and minimum.

[1] The Committee on Tests and Investigations recommends that the use of the Roberts No. 2 parabolic needle be permitted if it has been checked against the standard needle.

When desirable to vary the temperature, time, and weight, and, in order to provide for a uniform method of reporting results when variations are made, the samples shall be melted and cooled in air as above directed. They shall then be immersed in water or brine, as the case may require, for 1 hr. at the temperature desired. The following combinations are suggested:

At 0°C. (32°F.) 200-g. weight, 60 sec.

At 46.1°C. (115°F.) 50-g. weight, 5 sec.

LOSS ON HEATING OF OIL AND ASPHALTIC COMPOUNDS

(A. S. T. M. Standard Method, Serial Designation D 6–27)

The test is to determine the loss in weight (exclusive of water) of oil and asphaltic compounds when heated as hereinafter prescribed. The material under examination must therefore first be tested for water and if water is found to be present, it must be removed by suitable methods of dehydration before the material is subjected to the loss on heating test; or another sample obtained which is free from water.

The oven may be either circular or rectangular in form and may be heated by either gas or electricity. Its interior dimensions shall be as follows: Height, not less than 40.64 cm. (16 in.); width and depth or diameter, at least 5.08 cm. (2 in.) greater than the diameter of the revolving shelf.

It shall be well ventilated and shall be fitted with a window in the upper half of the door, so placed and of sufficient size to permit the accurate reading of the thermometer without opening the door. It shall also be provided with a perforated circular shelf preferably of approximately 24.8 cm. (9.75 in.) in diameter. This shelf shall be placed in the center of the oven and shall be suspended by a vertical shaft and provided with mechanical means for rotating it at the rate of 5 to 6 revolutions per minute. It shall be provided with recesses equidistant from the central shaft in which the tins containing the samples are to be placed.

The thermometer shall conform to the following requirements. These specifications cover a special thermometer graduated in Centigrade degrees, the range being 155 to 170°C.

Type: Etched stem, glass.

Liquid: Mercury.

Range and subdivision: 155 to 170°C. in 0.5°C.

Total Length: 150 to 154 mm. (5.90 to 6.06 in.).

Stem: Plain front, enamel back, suitable thermometer tubing. Diameter, 6.0 to 7.0 mm. (0.24 to 0.28 in.).

Bulb: Corning normal or equally suitable thermometric glass. Length, 10 to 15 mm. (0.39 to 0.59 in.). Diameter, 5.0 to 6.0 mm. (0.196 to 0.236 in.).

Distance to 0°C. line from bottom of bulb: 33 to 38 mm. (1.30 to 1.49 in.).

Distance to 155°C. line from bottom of bulb: 70 to 80 mm. (2.75 to 3.15 in.).

Distance to 170°C. line from top of thermometer: 20 to 30 mm. (0.79 to 1.18 in.).

Contraction chamber: To be long narrow type, top to be not more than 65 mm. (2.56 in.) above bottom of the bulb.

Expansion chamber: To permit heating the thermometer at least 25°C. above the highest temperature on the scale.

Filling above Mercury: Nitrogen gas.

Top Finish: Glass ring.

Graduation: All lines and figures clear cut and distinct. Each whole degree centigrade line to be longer than the remaining lines. Graduations are to be numbered at 0, 155, 163 and 170°C.

Immersion: Total.

Special marking: "A. S. T. M. Loss on Heat," a serial number and the manufacturer's name or trade mark shall be etched on the stem.

Scale error: The error at any point of the scale, when the thermometer is standardized as provided below shall not exceed 0.5°C.

Standardization: The thermometer shall be standardized at three points including 163°C. for total immersion.

Case: The thermometer shall be supplied in a suitable case on which shall appear the marking: "A. S. T. M. Loss on Heat, 155 to 170°C."

NOTE.—For the purpose of interpreting these specifications the following definitions apply:

The total length is the over-all length of the finished instrument.

The diameter is that measured with a ring gage.

The length of the bulb is the distance from the bottom of the bulb to the beginning of the enamel backing.

The top of the thermometer is the top of the finished instrument.

The container[1] in which the sample is to be tested shall be of tin, cylindrical in shape, and shall have a flat bottom. Its inside dimensions shall be substantially as follows: Diameter, 55 mm. (2.17 in.); depth, 35 mm. (1.38 in.). (A 3-oz. Gill-style ointment box, deep pattern, fulfills these requirements.)

The sample as received shall be thoroughly stirred and agitated, warming, if necessary, to insure a complete mixture before the portion for analysis is removed.

Weigh 50 g. of the water-free material to be tested, into a tared container conforming to the requirements of Sec. 4. Bring the oven to a temperature of 163°C. (325°F.), and place the tin box containing the sample in one of the recesses of the revolving shelf. The thermometer shall be immersed for the depth of its bulb in a separate 50-g. sample of the material under test, placed in a similar container, and shall be conveniently suspended from the vertical shaft. This sample shall rest in one of the recesses upon the same shelf and revolve with the sample or samples under test. Then close the oven and rotate the shelf 5 to 6 r.p.m. during the entire test. Maintain the temperature at 163°C. (325°F.) for 5 hr., then remove the sample from the oven, cool and weigh, and calculate the loss due to volatilization.

During the 5-hr. period the temperature shall not vary more than 1°C. All tests showing a greater variation in temperature shall be rejected.

[1] The Committee on Tests and Investigations of the Association of State Highway Officials recommends that when the test is applied to road oils for cold application a sample of 20 g. be used, and that the container be a standard 2-oz. ointment box 60 mm. in diameter and 20 mm. deep.

Under ordinary circumstances a number of samples having about the same degree of volatility may be tested at the same time. Samples varying greatly in volatility should be tested separately. Where extreme accuracy is required not more than one material should be placed simultaneously in the oven. Such duplicates shall check within the limits of accuracy given below. Results obtained on samples showing evidences of foaming during the test shall be rejected.

Up to 5 per cent loss in weight the results obtained may be considered as correct with 0.5. Above 5 per cent loss in weight the numerical limit of error increases 0.01 for every 0.5. per cent increase in loss by volatilization.

NOTE.—If additional periods of heating are desired, it is recommended that they be made in successive increments of 5 hr. each.

When the penetration of the sample after heating is required, melt the residue in the container at the lowest possible temperature and thoroughly mix by stirring, taking care to avoid incorporating air bubbles in the mass. Then bring it to the standard temperature and test as prescribed under the directions for the Standard Method of Test for Penetration of Bituminous Materials.

DISTILLATION OF BITUMINOUS MATERIALS SUITABLE FOR ROAD TREATMENT

(A. S. T. M. Tentative Standard, Serial Designation: D 20-28T)

APPARATUS

1. The apparatus consists of a flask, condenser tube, shield, receivers, and thermometers as specified in Sec. 2 to 6.

2. Flask:—The distillation flask shall be a side neck distilling flask, having the following dimensions:

Diameter of bulb, outside	86 mm.	± 1.5 mm.
Diameter of neck, inside	22 mm.	± 1.0 mm.
Diameter of tubulature, inside	10 mm.	± 0.5 mm.
Length of neck	43 mm.	± 1.0 mm.
Distance, top of neck to tubulature	25 mm.	± 1.0 mm.
Length of tubulature	220 mm.	± 5.0 mm.
Angle of tubulature	73 deg.	± 1.0 deg.

3. Condenser Tube.—The condenser tube shall be a suitable form of tapered glass tubing of the following dimensions:

Outside diameter of small end..12.5 mm.—permissible variation, ±1.5 mm.
Outside diameter of large end..28.5 mm.—permissible variation, ±3.0 mm.
Length.....360.0 mm.—permissible variation, ±4.0 mm.
Length of tapered part.....100.0 mm.—permissible variation, ±5.0 mm.

4. Shield.—A galvanized iron shield, lined with ⅛-in. asbestos shall be used to protect the flask from air currents and to prevent radiation. The cover (top) may be of transit board made in two parts, or it may be of galvanized iron lined with ⅛-in. asbestos.

5. Receiver.—The distillates will be collected in tared Erlenmeyer flasks having a capacity of 50 to 100 ml.

6. Thermometer.—The thermometer shall conform to the following requirements. These specifications cover a total-immersion thermometer graduated in either Centigrade or Fahrenheit degrees as specified, the range being from 0 to 400°C. or 30 to 760°F., respectively.

Type: Etched stem, glass.

Liquid: Mercury.

Range and subdivision: 0 to 400°C. in 1°C. or 30 to 760°F. in 2°F.

Total length.—3.78 mm to 3.84 m (14.88 to 15.12 in.)

Stem: Plain front, enamel back, suitable thermometer tubing. Diameter, 6.0 to 7.0 mm. (0.24 to 0.28 in.)

Bulb: Corning normal or equally suitable thermometric glass. Length 10 to 15 mm. (0.39 to 0.59 in.) Diameter, 5.0 to 6.0 mm. (0.20 to 0.24 in.).

Distance to 0°C. or 32°F. line from bottom of bulb: 25 to 35 mm. (0.98 to 1.38 in.).

Distance to 400°C. or 752°F. line from top of thermometer: 30 to 45 mm. (1.18 to 1.77 in.).

Filling above mercury: Nitrogen gas.

Top finish: Glass ring.

Graduation: All lines, figures, and letters clear cut and distinct. The first and each succeeding 5°C. or 10°F. line to be longer than the remaining lines. Graduations to be numbered at each multiple of 10°C. or 20°F.

Immersion: Total.

Special marking: "A. S. T. M. High Distillation," a serial number and the manufacturer's name or trade mark shall be etched on the stem.

Scale error: The error at any point of the scale up to 370°C. or 700°F. when the thermometer is standardized as provided below shall not exceed 1°C. or 2°F.

Standardization: The thermometer shall be standardized immersed in the testing bath to the top of the mercury column, at the ice point and at temperature intervals of approximately 50°C. or 100°F. up to 370°C. or 700°F.

Test for permanency of range: After being subjected to a temperature between 360 and 370°C. or 680 and 700°F. for 24 hrs., the accuracy shall be within the limit specified.

Case: The thermometer shall be supplied in a suitable case on which shall appear the marking: "A. S. T. M. High Distillation, 0 to 400°C." or "A. S. T. M. High Distillation, 30 to 760°F." according to the type of thermometer.

NOTE.—For the purpose of interpreting these specifications the following definitions apply:

The total length is the over-all length of the finished instrument.

The diameter is that measured with a ring gage.

The length of the bulb is the distance from the bottom of the bulb to the beginning of the enamel backing.

The top of the thermometer is the top of the finished instrument.

PREPARATION OF SAMPLE

7. The sample, as received, shall be thoroughly stirred and agitated, warmed, if necessary, to insure a complete mixture before the portion for analysis is removed.

8. The material may be tested for distillation without dehydration, if water present is not to exceed 2.0 per cent. If water is present in excess of 2.0 per cent, the bituminous material shall be dehydrated before distillation in accordance with the method for dehydration as given in Secs. 2 to 4 of the Standard Methods of Sampling and Analysis of Creosote Oil (Serial Designation: D 38) of the American Society for Testing Materials.

9. (*a*) The flask shall be supported on a tripod or rings over two sheets of 20-mesh gauze, 150 mm. square. It shall be connected to the condenser tube by a tight cork joint. The thermometer shall be inserted through a cork in the neck with the top of the bulb level with the lowest point of juncture of the tubulature and neck of the flask.

(*b*) The axis of the flask through the neck shall be vertical.

(*c*) The distance from the bulb of the thermometer to the outlet end of the condenser tube shall be not more than 600 nor less than 500 mm. The burner should be protected from draughts by a suitable shield or chimney.

10. (*a*) One hundred grams (100 g. $\pm$ 0.1 g.) of the sample shall be weighed into the flask, the apparatus assembled and heat applied so that the first drop comes over in from 5 to 15 min. The distillation shall be conducted at the rate of between 50 and 70 drops per minute and the distillate collected in weighted receivers. The condenser tube shall be warmed whenever necessary to prevent accumulation of solid distillates. The fraction shall be collected at the points designated by the specifications. The receivers shall be changed when the thermometer indicates the maximum temperature for each fraction. When the maximum specified temperature of the test is indicated by the thermometer, the flame shall be removed and any oil which has condensed in the condenser tube shall be drained into the last fraction.

(*b*) The residue shall remain in the flask with the cork and thermometer in position until no vapors are visible and it shall then be weighed. If tests of the residue are required, the flask shall then be inclined so that the residue will flow around the sides, thus collecting any condensed vapors that may be on the sides of the flask, after which the residue shall be poured into a suitable receptacle and covered. If the residue becomes so cool that it cannot be poured readily from the flask, it shall be reheated to a temperature not exceeding 125°C. by holding the bulb of the flask in a suitable bath and not by the application of flame.

For weighing the receivers and fractions, a balance accurate to at least 0.05 g. shall be used.

(*c*) During the progress of the distillation the thermometer shall remain in its original position. No correction shall be made for the emergent stem of the thermometer.

(*d*) The results of the distillation test shall be reported in percentages by weight of water-free material. The following fractions are usually reported:

Up to 170°C.
170 to 235°C.
235 to 270°C.
270 to 300°C.
Residue

SOFTENING POINT OF BITUMINOUS MATERIALS

(Ring-and-Ball Method)

(A. S. T. M. Standard Method, Serial Designation: D 36-26)

1. The softening of bituminous materials generally takes place at no definite moment or temperature. As the temperature rises, they gradually and imperceptibly change from a brittle or exceedingly thick and slow-flowing material to a softer and less viscous liquid. For this reason the determination of the softening point must be made by a fixed, arbitrary and closely defined method if the results obtained are to be comparable.

Apparatus

2. The apparatus shall consist of the following:

(*a*) A brass ring 15.875 mm. (5/8 in.) in inside diameter and 6.35 mm. (1/4 in.) deep; thickness of wall, 2.38 mm. (3/32 in.); permissible variation on inside diameter and thickness of ring 0.25 mm. (0.01 in.). This ring shall be attached in a convenient manner to a No. 13 B. & S. gage brass wire (diameter 1.83 mm. = 0.072 in.).

(*b*) A steel ball 9.63 mm. (3/8 in.) in diameter weighing between 3.45 and 3.55 g.

(*c*) A glass vessel, capable of being heated, not less than 8.5 cm. (3.34 in.) in diameter and measuring 10.5 cm. (4.13 in.) in depth from the bottom of the flare. (A 600-cc. beaker, low form, meets this requirement.)

(*d*) A thermometer which shall conform to the following requirements. These specifications cover a special thermometer graduated in either Centigrade or Fahrenheit degrees as specified, the ranges being −2 to +80°C. or +30 to +180°F., respectively.

Type: Etched stem, glass.

Liquid: Mercury.

Range and subdivision: −2 to +80°C. in 0.2°C. or +30 to +180°F. in 0.5°F.

Total length: 378 to 384 mm. (14.88 to 15.12 in.).

Stem: Plain front, enamel back, suitable thermometer tubing. Diameter, 6.0 to 7.0 mm. (0.24 to 0.28 in.).

Bulb: Corning normal or equally suitable thermometric glass.

Length, 9 to 14 mm. (0.35 to 0.55 in.)

Diameter, 4.5 to 5.5 mm. (0.18 to 0.22 in.).

Distance to 0°C. or 32°F. line from bottom of bulb: 75 to 90 mm. (2.95 to 3.54 in.).

Distance to 80°C. or 176°F. line from top of thermometer: 30 to 45 mm. (1.18 to 1.77 in.).

Expansion chamber: To permit heating the thermometer at least 50°C. (90°F.) above highest temperature on scale.

Filling above mercury: Nitrogen gas.

Top finish: Glass ring.

Graduation: All lines, figures, and letters clear cut and distinct. Each whole degree Centigrade or Fahrenheit line to be longer than the remaining lines. Graduations to be numbered at each multiple of 2°C. or 5°F.

Immersion: Total.

Special marking: "A. S. T. M. Low S. P.," a serial number and the manufacturer's name or trade mark shall be etched on the thermometer.

Scale error: The error at any point of the scale when the thermometer is standardized as provided below shall not exceed 0.2°C. or 0.4°F.

Standardization: The thermometer shall be standardized immersed in the testing bath to the top of the mercury column, at the ice point and at temperature intervals of approximately 20°C. or 40°F.

Case.—The thermometer shall be supplied in a suitable case on which shall appear the marking: "A. S. T. M. Low S. P., −2 to +80°C.," or "A. S. T. M. Low S. P., +30 to +180°F." according to the type of thermometer.

NOTE.—For the purpose of interpreting these specifications the following definitions apply:

The total length is the over-all length of the finished instrument.

The diameter is that measured with a ring gage.

The length of the bulb is the distance from the bottom of the bulb to the beginning of the enamel backing.

The top of the thermometer is the top of the finished instrument.

PREPARATION OF SAMPLE

3. The sample shall be melted and stirred thoroughly, avoiding incorporating air bubbles in the mass, and then poured into the ring so as to leave an excess on cooling. The ring, while being filled, should rest on a brass plate which has been amalgamated to prevent the bituminous material from adhering to it. After cooling, the excess material shall be cut off cleanly with a slightly heated knife.

PROCEDURE

(A) Bituminous Materials Having Softening Points 80°C. (176°F.) or below

4. Fill the glass vessel to a depth of substantially 8.25 cm. (3.25 in.) with freshly boiled, distilled water at 5°C. (41°F.). Suspend the ring containing the sample in the water so that the lower surface of the filled ring is exactly 2.54 cm. (1 in.) above the bottom of the glass vessel and its upper surface is 5.08 cm. (2 in.) below the surface of the water. Place the ball in the water but not on the specimen. Suspend the thermometer so that the bottom of the bulb is level with the bottom of the ring and within 0.635 cm. (¼ in.), but not touching the ring. Maintain the temperature of the water at 5°C. (41°F.) for 15 min. With suitable forceps, place the ball in the center of the upper surface of the bitumen in the ring, thus completing the assembly.

5. Apply the heat in such a manner that the temperature of the water is raised 5°C. (9°F.) each minute.

6. The temperature recorded by the thermometer at the instant the bituminous material touches the bottom of the glass vessel shall be reported as the softening point. No correction shall be made for emergent stem.

7. The rate of rise of temperature shall be uniform and shall not be averaged over the period of the test. The maximum permissible variation for any minute period after the first three shall be ± 0.5°C. (0.9°F.). All

tests in which the rate of rise in temperature exceeds these limits shall be rejected.

(*B*) *Bituminous Materials Having Softening Points above* 80°*C.* (176°*F.*).

8. The same method as given under (*A*) shall be employed except that U. S. P. glycerin shall be used instead of water, and the starting point of the glycerin bath shall be 32°C. (89.6°F.). The bath shall be brought to this temperature and thoroughly agitated, then the apparatus and specimens shall be placed in the bath which shall be maintained under agitation at the starting temperature for 15 min., after which the assembly shall be completed by placing the ball on the center of the specimen and the test carried on as in (*A*). In applying the heat, the ring apparatus shall be placed off the center of the container and the burner placed midway between the center and edge of the beaker away from the specimen.

The thermometer shall conform to the following requirements. These specifications cover a special thermometer graduated in either Centigrade or Fahrenheit degrees as specified, the ranges being 30 to 160°C. or 85 to 320°F., respectively:

Type: Etched stem, glass.

Liquid: Mercury.

Range and Subdivision: 30 to 160°C. in 0.5°C. or 85 to 320°F. in 1°F.

Total length: 378 to 384 mm. (14.88 to 15.12 in.).

Stem: Plain front, enamel back, suitable thermometer tubing. Diameter 6.0 to 7.0 mm. (0.24 to 0.28 in.).

Bulb: Corning normal or equally suitable thermometric glass. Length, 9 to 14 mm. (0.35 to 0.55 in.).

Diameter, 4.5 to 5.5 mm. (0.18 to 0.22 in.).

Distance to 30°C. or 86°F. line from bottom of bulb: 75 to 90 mm. (2.95 to 3.54 in.).

Distance to 160°C. or 320°F. line from top of thermometer: 30 to 45 mm. (1.18 to 1.77 in.).

Expansion chamber: To permit heating the thermometer at least 50°C. (90°F.) above the highest temperature on the scale.

Filling above mercury: Nitrogen gas.

Top finish: Glass ring.

Graduation: All lines, figures, and letters clear cut and distinct. Each whole degree Centigrade line or the first and each succeeding 5°F. line to be longer than the remaining lines. Graduations to be numbered at each multiple of 5°C. or 10°F.

Immersion: Total.

Special marking: "A. S. T. M. High S. P.," a serial number and the manufacturer's name or trade mark shall be etched on the thermometer.

Scale error: The error at any point of the scale when the thermometer is standardized as provided below shall not exceed 0.3°C. or 0.5°F.

Standardization: The thermometer shall be standardized, immersed in the testing bath to the top of the mercury column, at intervals of approximately 40°C. or 70°F.

Case: The thermometer shall be supplied in a suitable case on which shall appear the marking: "A. S. T. M. High S. P., 30 to 160°C.," or "A. S. T. M. High S. P., 85 to 320°F." according to the type of thermometer.

NOTE.—For the purpose of interpreting these specifications the following definitions apply:

The total length is the over-all length of the finished instrument.

The diameter is that measured with a ring gage.

The length of the bulb is the distance from the bottom of the bulb to the beginning of the enamel backing.

The top of the thermometer is the top of the finished instrument.

PRECAUTIONS

9. The use of freshly boiled distilled water is essential, as otherwise air bubbles may form on the specimen and affect the accuracy of the results. Rigid adherence to the prescribed rate of heating is absolutely essential in order to secure accuracy of results.

A sheet of paper placed on the bottom of the glass vessel and conveniently weighted will prevent the bituminous material from sticking to the glass vessel, thereby saving considerable time and trouble in cleaning.

ACCURACY

10. The limit of accuracy of the test is ± 0.5°C. (0.9°F.).

DETERMINATION OF BITUMEN SOLUBLE IN CARBON DISULPHIDE

This test consists in dissolving the bitumen in carbon disulphide and recovering any insoluble matter by filtering the solution through an asbestos felt. The form of Gooch crucible best adapted for the determination is 4.4 cm. wide at the top, tapering to 3.6 cm. at the bottom, and is 2.5 cm. deep.

For preparing the felt, the asbestos is cut with scissors into pieces not exceeding 1 cm. in length, after which it is shaken up with just sufficient water to pour easily.

The crucible is placed in a filter flask and filled with the suspended asbestos, which is allowed to settle for a few moments. A light suction is then applied to draw off all the water and leave a firm mat of asbestos in the crucible. More of the suspended material is added, and the operation is repeated until the felt is so dense that it scarcely transmits light when held so that the bottom of the crucible is between the eye and the source of light. The felt should then be washed several times with water and drawn firmly against the bottom of the crucible by an increased suction. The crucible is removed to a drying oven for a few minutes, after which it is ignited at a red heat over a Bunsen burner, cooled in a desiccator, and weighed.

From 1 to 2 g. of bitumen or about 10 g. of an asphalt topping or rock asphalt is now placed in the Erlenmeyer flask, which has been previously weighed, and the accurate weight of the sample is obtained. One hundred cubic centimeters of chemically pure carbon disulphide is poured into the flask in small portions, with continual agitation, until all lumps disappear and nothing adheres to the bottom. The flask is then corked and set aside for 15 min.

After being weighed, the Gooch crucible containing the felt is set up over the dry-pressure flask and the solution of bitumen in carbon disulphide is decanted through the felt with light suction or without suction, by gradually tilting the flask, with care not to stir up any precipitate that may have settled out. At the first sign of any sediment coming out, the decantation is stopped and the filter allowed to drain. A small amount of carbon disulphide is then washed down the sides of the flask, after which the precipitate is brought upon the felt and the flask scrubbed, if necessary, with a feather or "policeman" to remove all adhering material. The contents of the crucible are washed with carbon disulphide, until the washings run colorless. Suction is then applied until there is practically no odor of carbon disulphide in the crucible after which the outside of the crucible is cleaned with a cloth moistened with a small amount of the solvent.

The crucible and contents are dried in the hot-air oven at 100°C. for about 20 min., cooled in a desiccator, and weighed. If any appreciable amount of insoluble matter adheres to the flask, it should also be dried and weighed, and any increase over the original weight of the flask should be added to the weight of insoluble matter in the crucible.

The total weight of insoluble material may include both organic and mineral matter. The former, if present, is burned off by ignition at a red heat until no incandescent particles remain, thus leaving the mineral matter or ash, which can be weighed on cooling.

The difference between the total weight of material insoluble in carbon disulphide and the weight of substance taken equals the total bitumen, and the percentage weights are calculated and reported as total bitumen, and organic and inorganic matter insoluble on the basis of the weight of material, taken for analysis.

This method is quite satisfactory for straight oil and tar products, but where certain natural asphalts are present, it will be found practically impossible to retain all of the finely divided mineral matter on an asbestos felt. It is, therefore, generally more accurate to obtain the result for total mineral matter by direct ignition of a 1-g. sample in a platinum crucible or to use the result for ash obtained in the fixed carbon test. The total bitumen is then determined by deducting from 100 per cent the sum of the percentages of total mineral matter and organic matter insoluble.

If the presence of a carbonate mineral is suspected, the percentage of mineral matter may be most accurately obtained by treating the ash from the fixed carbon determination with a few drops of ammonium carbonate solution, drying at 100°C., then heating for a few minutes at a dull red heat, cooling, and weighing again.

When difficulty in filtering is experienced—as for instance, when Trinidad asphalt is present in any amount—a period of longer subsidence than 15 min. is necessary, and the following method proposed by the Committee on Standard Tests for Road Materials of the American Society for Testing Materials is recommended:

From 2 to 15 g. (depending on the richness in bitumen of the substance) is weighed into a 150-cc. Erlenmeyer flask, the tare of which has been previously ascertained, and treated with 100 cc. of carbon disulphide. The flask is then loosely corked and shaken from time to time until practically all

large particles of the material have been broken up, when it is set aside and not disturbed for 48 hr. The solution is then decanted off into a similar flask that has been previously weighed, as much of the solvent being poured off as possible without disturbing the residue. The first flask is again treated with fresh carbon disulphide and shaken as before, when it is put away with the second flask and not disturbed for 48 hr.

At the end of this time the contents of the two flasks are carefully decanted off upon a weighed Gooch crucible fitted with an asbestos filter, the contents of the second flask being passed through the filter first. The asbestos filter shall be made of ignited long-fiber amphibole, packed in the bottom of a Gooch crucible to the depth of not over $\frac{1}{8}$ in. After passing the contents of both flasks through the filter, the two residues are shaken with more fresh carbon disulphide and set aside for 24 hr. without disturbing, or until it is seen that a good subsidation has taken place, when the solvent is again decanted off upon the filter. This washing is continued until the filtrate or washings are practically colorless.

The crucible and both flasks are then dried at 125°C. and weighed. The filtrate containing the bitumen is evaporated, the bituminous residue burned, and the weight of the ash thus obtained added to that of the residue in the two flasks and the crucible. The sum of these weights deducted from the weight of substance taken gives the weight of bitumen extracted.

DETERMINATION OF BITUMEN INSOLUBLE IN PARAFFIN NAPHTHA

This determination is made in the same general manner as the total bitumen determination, except that 100 cc. of 86° to 88°Bé. paraffin naphtha, at least 85 per cent distilling between 35°C. and 65°C., is employed as a solvent instead of carbon disulphide.

Considerable difficulty is sometimes experienced in breaking up some of the heavy semi-solid bitumens; the surface of the material is attacked, but it is necessary to remove some of the insoluble matter in order to expose fresh material to the action of the solvent. It is, therefore, advisable to heat the sample after it is weighed, allowing it to cool in a thin layer around the lower part of the flask. If difficulty is still experienced in dissolving the material, a rounded glass rod will be found convenient for breaking up the undissolved particles.

Not more than one-half of the total amount of naphtha required should be used until the sample is entirely broken up. The balance of the 100 cc. is then added, and the flask is twirled a moment in order to mix the contents thoroughly, after which it is corked and set aside for 30 min.

In making the filtration the utmost care should be exercised to avoid stirring up any of the precipitate, in order that the filter may not be clogged and that the first decantation may be as complete as possible. The sides of the flask should then be quickly washed down with naphtha and, when the crucible has drained, the bulk of insoluble matter is brought upon the felt.

Suction may be applied when the filtration by gravity almost ceases, but should be used sparingly, as it tends to clog the filter by packing the precipitate too tightly. The material on the felt should never be allowed to run entirely dry until the washing is completed, as shown by the colorless filtrate.

When considerable insoluble matter adheres to the flask no attempt should be made to remove it completely. In such cases the adhering material is merely washed until free from insoluble matter, and the flask is dried with the crucible at 100°C. for about 1 hr., after which it is cooled and weighed. The percentage of bitumen insoluble is reported upon the basis of total bitumen taken as 100.

The difference between the material insoluble in carbon disulphide and in the naphtha is the bitumen insoluble in the latter. Thus, if in a certain instance it is found that the material insoluble in carbon disulphide amounts to 1 per cent and that 10.9 per cent is insoluble in naphtha, the percentage of bitumen insoluble would be calculated as follows:

$$\frac{\text{Bitumen insoluble in naphtha}}{\text{Total bitumen}} = \frac{10.9 - 1}{100 - 1} = \frac{9.9}{99} - 10 \text{ per cent.}$$

BITUMEN INSOLUBLE IN CARBON TETRACHLORIDE

This determination is conducted in exactly the same manner as the determination of bitumen soluble in carbon disulphide, using 100 cc. of chemically pure carbon tetrachloride as a solvent in place of carbon disulphide.

The percentage of bitumen insoluble is reported upon the basis of total bitumen taken as 100 in accordance with the method described in the test for bitumen insoluble in naphtha.

SPECIFIC VISCOSITY DETERMINATION

The viscosity of fluid bituminous road materials may be determined at any suitable temperature by means of the Engler viscosimeter.

As all viscosity determinations are compared with that of water at 25°C., the apparatus should be previously calibrated as follows:

The cup and outlet tube should first be scrupulously cleaned. A piece of soft tissue paper is convenient for cleaning the latter. The stopper is then inserted in the tube and the cup filled with water at 25°C. to the top of the projections. The measuring cylinder should be placed directly under the outflow tube so that the material, upon flowing out, will not touch the sides, and the stopper may then be removed. The time required both for 50 and 100 cc. to run out should be ascertained by means of a stop watch, and the results so obtained should be checked a number of times. The time required for 50 cc. of water should be about 11 sec. and for 100 cc. about 22.8 sec.

Bituminous road materials are tested in the same manner as water, and the temperature at which the test is made is controlled by the bath. The material should be brought to the desired temperature and maintained there for at least 3 min. before making the test. The results are expressed as specific viscosity compared with water at 25°C., as follows:

Specific viscosity at A°C. =

$$\frac{\text{seconds for passage of the first 50 cc.}}{\text{seconds for passage of same volume of water at 25°C.}}$$

METHOD FOR EXAMINATION OF BITUMINOUS MIXTURES

A. Centrifugal Method

The aggregate is prepared for analysis by heating it in an enameled-ware pan on the hot plate until it is sufficiently soft to be thoroughly disintegrated

by means of a large spoon. Care must be taken, however, that the individual particles are not crushed. If a section of pavement is under examination, a piece weighing somewhat over 1 kg. may be cut off with hammer and chisel. The disintegrated aggregate is then allowed to cool, after which a sufficient amount is taken to yield on extraction from 50 to 60 g. of bitumen. It is placed in the iron bowl of a centrifugal extractor and a ring three-fourths of an inch wide, cut from the felt paper, is fitted on the rim, after which the brass plate is placed in position and drawn down tightly by means of the milled nut.

If the bitumen is to be recovered and examined, the felt ring should be previously treated in the empty extractor with a couple of charges of carbon disulphide in order to remove any small amount of grease or resin that may be present, although a proper grade of felt should be practically free from such products.

The bowl is now placed on the motor shaft and the slot and pin are carefully locked. An empty bottle is placed under the spout and 150 cc. of carbon disulphide (carbon tetrachloride, benzol, or chloroform may also be used as solvents) is poured into the bowl through the small holes. The cover is put on the copper box, and after allowing the material to digest for a few minutes, the motor is started slowly at first in order to permit the aggregate to distribute uniformly. The speed should then be increased sufficiently by means of the regulator to cause the dissolved bitumen to flow from the spout in a thin stream.

When the first charge has drained, the motor is stopped and a fresh portion of disulphide is added. This operation is repeated from four to six times with 150 cc. of disulphide. With a little experience the operator can soon gage exactly what treatment is necessary for any given material.

When the last addition of solvent has drained off, the bowl is removed and placed with the brass plate uppermost on a sheet of manilla paper. The brass plate and felt ring are carefully laid aside on the paper and, when the aggregate is thoroughly dry, it can be brushed on a pan of the rough balance and weighed.

The difference between this weight and the original weight taken shows the amount of bitumen extracted. The aggregate may then be tested as occasion requires.

Ash correction shall be made in the following manner: The total solution of bitumen from the extractor is well stirred and rapidly measured and an aliquot portion taken, usually 100 cc. and poured into a previously weighed suitable flat-bottom dish, preferably quartz. The solvent is evaporated over a very low flame and the residual coke is then ignited with a burner capable of furnishing high temperature, such as a Meeker. (Caution: When an inflammable solvent is used evaporation should be conducted on a steam bath and care should be taken that no flames are in the immediate vicinity.) The dish and contents are then cooled in a desiccator and the percentage of ash calculated.

B. Hot Extraction Method

The aggregate is prepared for analysis by heating it in a tin dish on the top plate until it is sufficiently soft to be disintegrated by means of a large spoon.

The disintegrated aggregate is then allowed to cool. Five hundred grams of mixtures containing particles larger than ¾ in. in diameter (or 200 g., if the mixtures contain no particles larger than ¾ in.) are then closely packed in the wire basket of the New York Testing Laboratory extractor, and covered with a disc or wad of absorbent cotton or felt.

From 175 to 200 cc. of carbon disulphide are next placed in the inside vessel, in which the wire basket should be suspended. The top is then placed in position and cooling water circulated through it. Heat is applied by means of the electric light bulb. The solvent is boiled in the lower part of the extractor and condenses on the under surface of the top, from which it drips upon the wad of absorbent cotton and then percolates through the sample. A complete extraction may be made in 3 hr. At the end of this time the apparatus is allowed to cool and the basket containing the extracted aggregate carefully removed.

After thoroughly drying, the aggregate is placed upon a pan of the rough balance and weighed. The difference between this weight and the original weight taken shows the amount of bitumen extracted which is calculated upon a percentage basis of the original.

This figure should be corrected for fine material matter which passes through the meshes of the wire basket as follows: The solution of extracted bitumen is thoroughly agitated and measured in a glass graduate. Five or ten cubic centimeters are then poured into a weighed platinum crucible or dish, burned, and ignited to ash. The amount of mineral matter in the entire solution may then be calculated from the amount of ash produced from that portion ignited. The total percentage of such ash is then deducted from the percentage of bitumen already calculated in order to obtain the true percentage of bitumen. The amount of this correction will ordinarily vary from 0.1 per cent in uniformly coarse aggregates to 1 or 2 per cent in the analysis of aggregates containing a considerable amount of very fine mineral matter.

SUGGESTED METHOD FOR EXAMINATION OF BITUMINOUS MORTARS

Bituminous mortars may be extracted by the use of bronze tubes which are capable of being whirled in a type of centrifuge similar to the Babcock milk tester. This method is based on decantation of the supernatant solvent. The difference between the final aggregate and the original amount taken gives the amount of bitumen extracted which is subject to correction of the amount of ash determined from the washings. Ash correction to be made as given under *A*.

GLOSSARY

The following words and terms are employed in highway engineering and have been defined by a special committee of the American Society of Civil Engineers or by the American Society for Testing Materials. For many of the words both have agreed on the definition.

Asphalts.—Solid or semi-solid native bitumens, solid or semi-solid bitumens obtained by refining petroleum, or solid or semi-solid bitumens which are combinations of the bitumens mentioned with petroleums or derivatives thereof, which melt upon the application of heat and which consist of a mixture of hydrocarbons and their derivatives of complex structure, largely cyclic and bridge compounds.

Native Asphalt.—Asphalt occurring as such in nature.

Asphalt-block Pavement.—One having a wearing course of previously prepared blocks of asphaltic concrete.

Asphalt Cement.—A fluxed or unfluxed asphalt specially prepared as to quality and consistency for direct use in the manufacture of bituminous pavements, and having a penetration at 25°C. (77°F.) of between 5 and 250, under a load of 100 g. applied for 5 sec. **or,**

Asphalt Cement.—A fluxed or unfluxed asphaltic material, especially prepared as to quality and consistency, suitable for direct use in the manufacture of asphaltic pavements, and having a penetration of between 5 and 250.

Asphaltenes.—The components of the bitumen in petroleums, petroleum products, malthas, asphalt cements, and solid native bitumens, which are soluble in carbon disulphide but insoluble in paraffine naphthas.

Asphaltic.—Similar to, or essentially composed of, asphalt.

Base.—Artificial foundation.

Binder.—A foreign or fine material introduced into the mineral portion of the wearing surface for the purpose of assisting the road metal to retain its integrity under stress, as well as, perhaps, to aid in its first construction. (2) The course in a sheet-asphalt pavement, frequently used between the concrete foundation and the sheet-asphalt mixture of graded sand and asphalt cement.

Bitumens.—Mixtures of native or pyrogenous hydrocarbons and their non-metallic derivatives, which may be gases, liquids, viscous liquids, or solids and which are soluble in carbon disulphide.

Bituminous.—Containing bitumen or constituting the source of bitumen.

Bituminous Cement.—A bituminous material suitable for use as a binder having cementing qualities which are dependent mainly on its bituminous character.

Bituminous Concrete Pavement.—One composed of stone, gravel, sand shell, or slag, or combinations thereof, and bituminous materials incorporated together by mixing methods.

Bituminous Emulsion.—A liquid mixture in which minute globules of bitumen are held in suspension in water or a watery solution.

Bituminous Macadam Pavement.—One having a wearing course of macadam with the interstices filled by penetration methods with a bituminous binder.

Bituminous Material.—Material containing bitumen as an essential constituent.

Bituminous Pavement.—One composed of stone, gravel, sand, shell, or slag, or combinations thereof, and bituminous materials incorporated together.

Bituminous Surface.—A superficial coat of bituminous material with or without the addition of stone or slag chips, gravel, sand, or material of similar character.

Blanket.—See "Carpet."

Bleeding.—The exudation of bituminous material on the roadway surface after construction.

Blown Petroleums.—Semi-solid or solid products produced primarily by the action of air upon liquid native bitumens which are heated during the blowing process.

Bond.—The combined action of inertia, friction, and of the forces of adhesion and cohesion which helps the separate particles composing a crust or pavement to resist separation under stress. Mechanical bond is the bond produced almost wholly, in a well-built broken-stone macadam road, by the interlocking of angular fragments of stone and the subsequent filling of the remaining interstices with the finer particles.

Bound.—Bonded.

Brick Pavement.—One having a wearing course of paving bricks or blocks.

Bridge.—A structure for the purpose of carrying traffic over a gap in the roadbed measuring 10 ft. or more in the clear span.

Camber of a Bridge.—The rise of its center above a straight line through its ends.

Camber of a Road.—See "Crown."

Carbenes.—The components of the bitumen in petroleums, petroleum products, malthas, asphalt cements and solid; native bitumens, which are soluble in carbon disulphide but insoluble in carbon tetrachloride.

Carpet.—A bituminous surface of appreciable thickness, generally formed on top of a roadway by the application of one or more coats of bituminous material with gravel, sand, or stone chips added.

Cement.—An adhesive substance used for uniting particles of other materials to each other. Ordinarily applied only to calcined "cement rock," or to artifically prepared, calcined, and ground mixtures of limestone and siliceous materials. Sometimes used to designate bituminous binder used in bituminous pavements, when the expression "bituminous cement" is understood to be meant.

Cemented.—Bonded. Referring to water-bound macadam, the term "cemented" is used to designate that condition existing when, after rolling the stone forming the crust, the remaining voids have been filled with the finer sizes, and the stone dust or "flour" has, under the action of water, taken a "set," as does cement itself.

Cement-concrete.—An intimate mixture of gravel, shell, slag, or broken stone particles with certain proportions of sand or similar material, cement, and water, made previous to placing.

Cement-concrete Pavement.—One having a wearing course of hydraulic cement-concrete.

Chert.—Compact siliceous rock formed of calcedonic or opaline silica, or both.

Chips.—Small angular fragments of stone containing no dust.

Clinker.—Generally a fused or partly fused by-product of the combustion of coal, but also including lava and portland-cement clinker, and partly vitrified slag and brick.

Coal Tar.—The mixture of hydrocarbon distillates, mostly unsaturated ring compounds, produced in the destructive distillation of coal.

Coat.—See "Carpet." (1) The total result of one or more single-surface applications. (2) To apply a coat.

Coke-oven Tar.—Coal tar produced in by-product coke ovens in the manufacture of coke from bituminous coal.

Consistency.—The degree of solidity or fluidity of bituminous materials.

Course.—One or more layers of road metal spread and compacted separately for the formation of the road or pavement. Courses are usually referred to in the order of their laying as first course, third course, etc. Also a single row of blocks in a pavement.

Crown.—The rise in cross-section from the lowest to the highest part of the finished roadway. It may be expressed either as so many inches (or tenths of a foot), or as a rate per foot of distance from side to center, *i.e.*, "the crown is 4 in.," or "the crown is ½ in. to the foot."

Crusher-run.—The total unscreened product of a stone crusher.

Crusher-run Stone.—The product of a stone crusher, unscreened except for the removal of the particles smaller than remaining on about a ¼-in. screen.

Crust.—That portion of a macadam or similar roadway above the foundation consisting of the road metal proper with its bonding agent or binder.

Culvert.—A structure for the purpose of carrying traffic over a gap in the roadbed, measuring less than 10 ft. in clear span.

Cut-back Products.—Petroleum, or tar residuums, which have been fluxed, each with its own or similar distillates.

Dead Oils.—Oils with a density greater than water which are distilled from tars.

Ditch.—The open-side drain of a roadway, usually deep in proportion to its width, and unpaved.

Drainage.—Provision for the disposition of water. Side drainage. That along the sides of the roadway. Sub- or underdrainage. That below the surface. Surface drainage. That on the roadway or ground surface. V-drainage. That provided by the construction of troughs in the subgrade of the roadway, which troughs are like a "V," with flat sloping sides, and are filled with stone.

Dust Layer.—Material applied to a roadway for temporarily preventing the formation or dispersion under traffic of distributable dust.

Earth Road.—A roadway composed of natural earthy material.

Emulsion.—A combination of water and oily material made miscible with water through the action of a saponifying or other agent.

Expansion Joint.—A separation of the mass of a structure, usually in the form of a joint filled with elastic material, which will provide opportunity for slight movement in the structure.

Fat.—Containing an excess. A fat asphalt mixture is one in which the asphalt cement is in excess and the excess is clearly apparent.

Fixed Carbon.—The organic matter of the residual coke obtained upon burning hydrocarbon products in a covered vessel in the absence of free oxygen.

Flour.—Finely ground rocks or minerals pulverized to an impalpable product.

Flushing.—(1) Completely filling the voids. (2) Washing a pavement with an excess of water.

Flush Coat.—See "Seal Coat."

Flux.—Bitumens, generally liquid, used in combination with harder bitumens for the purpose of softening the latter.

Footway.—The portion of the highway devoted especially to pedestrians. A sidewalk.

Foundation.—The portion of the roadway below and supporting the crust or pavement.

Artificial Foundation.—That layer of the foundation especially placed on the subgrade for the purpose of reinforcing the supporting power of the latter itself, and composed of material different from that of the subgrade proper.

Natural Foundation.—The natural earthy material below and supporting the artificial foundation or, if there is no artificial foundation, the crust or pavement.

Free Carbon in Tars.—Organic matter which is insoluble in carbon disulphide.

Gas-house Coal Tar.—Coal tar produced in gas-house retorts in the manufacture of illuminating gas from bituminous coal.

Grade.—(1) The profile of the center of the roadway, or its rate of rise or fall. (2) Elevation. (3) To establish a profile by cuts and fills or earthwork. (4) To arrange by sizes, broken stone, gravel, sand, or combinations of such materials.

Granite.—A granitoid igneous rock consisting of quartz, orthoclase, more or less oligoclase, biotite, and muscovite.

Granitoid.—A textural term to describe those igneous rocks which are entirely composed of recognizable minerals.

Gutter.—The artificially surfaced and generally shallow waterway provided usually at the sides of the roadway for carrying surface drainage. Occasionally used synonymously with "ditch," but incorrectly so, as "gutters" are always paved or otherwise surfaced, and ditches are not.

Haunches.—The sides of flanks of a roadway. Sometimes also called "quarters."

Highway.—The entire right of way devoted to public travel, including the sidewalks and other public spaces, if such exist.

Layer.—A course made in one application.

Liquid Bituminous Materials.—Those having a penetration of 25°C. (77°F.), under a load of 100 g. applied for 5 sec., of more than 10, and a penetration at 25°C. (77°F.), under a load of 50 g. applied for 1 sec., of not more than 350.

Macadam.—A road crust composed of stone or similar material broken into irregular angular fragments compacted together so as to be interlocked and mechanically bound to the utmost possible extent.

Mastic.—A mixture of bituminous materials and fine mineral matter suitably made for use in highway construction and for application in a heated condition.

Mat.—See "Carpet."

Matrix.—The binding material or mixture of binding material and fine aggregate in which the large aggregate is embedded or held in place.

Mesh.—The square opening of a sieve.

Metal.—See "Road Metal."

Mortar.—A mixture of fine material such as sand, cement, and water or other liquid suitably proportioned and incorporated together for the purpose for which it is used.

Mush.—A greasy mud sometimes found on bituminous crusts.

Normal Temperature.—As applied to laboratory observations of the physical characteristics of bituminous materials, is 25°C. (77°F.).

Oil-gas Tars.—Tars produced by cracking oil vapors at high temperatures in the manufacture of oil gas.

Palliative.—A short-lived dust layer.

Patching.—Repairing or restoring small isolated areas in the surface of the metaled or paved portion of the highway.

Pavement.—The wearing course of the roadway or footway, when constructed with a cement or bituminous binder, or composed of blocks or slabs, together with any cushion or "binder course."

Penetration.—The consistency of a bituminous material expressed as the distance that a standard needle vertically penetrates a sample of the material under known conditions of loading, time, and temperature. Where the conditions of test are not specifically mentioned, the load, time, and temperature are understood to be 100 g., 5 sec., 25°C. (77°F.) and the units of penetration to indicate hundredths of centimeters.

Penetration Method.—The method of constructing a bituminous macadam pavement by pouring or grouting the bituminous material into the upper course of the road metal before the binding of the latter has been completed.

Petroleum.—Liquid bitumen occurring as such in nature.

Pitches.—Solid residues produced in the evaporation or distillation of bitumens, the term being usually applied to residues obtained from tars.

Hard pitch.—Pitch showing a penetration of not more than ten.

Soft pitch.—Pitch showing a penetration of more than ten.

Pocket.—A hole or depression in the wearing course.

Pot-hole.—A hole extending below the wearing course.

Profile.—A longitudinal section of a highway, generally taken along the center line.

Quarters.—The four sections of equal width which, side by side, make up the total width of a roadway.

Raveling.—The loosening of the metal composing the crust.

Refined Tar.—Tar freed from water by evaporation or distillation which is continued until the residue is of desired consistency; or a product produced by fluxing tar residuum with tar distillate.

Renewals.—Extensive repairs over practically the whole surface of the metaled or paved portion of the highway.

Repairs.—The restoration or mending of a considerable amount of the metaled or paved portion of the highway, but not usually of a majority of the surface area. More extensive than "Patching" but less so than "Renewals."

Resurfacing.—The renewal of the surface of the crust or pavement.

Road.—A highway outside of an urban district.

Roadbed.—The natural foundation of a roadway.

Road Metal.—Broken stone, gravel slag, or similar material used in road and pavement construction and maintenance.

Roadway.—That portion of a highway particularly devoted to the use of vehicles.

Rock Asphalt.—Sandstone or limestone naturally impregnated with asphalt.

Rock-asphalt Pavement.—A wearing course composed of broken or pulverized rock asphalt with or without the addition of other bituminous materials.

Rubble.—Rough stones of irregular shapes and sizes, broken from larger masses either naturally or artificially, as by geological action, in quarrying, or in stone cutting or blasting.

Sand-clay Road.—A roadway composed of an intimate mixture of sand and clay.

Scarify.—To loosen and disturb superficially.

Seal Coat.—A final superficial application of bituminous material during construction to a bituminous pavement.

Setting Up.—The relatively quick change such as takes place in a bituminous material after its application to a roadway, indicated by its hardening after cooling and exposure to atmospheric and traffic conditions, as opposed to the slower changes later occurring gradually and almost imperceptibly.

Shaping.—Trimming up and preparing a subgrade preparatory to applying the first course of the road metal or artificial foundation.

Sheet-asphalt Pavement.—One having a wearing course composed of asphalt cement and sand of predetermined grading, with or without the addition of fine material, incorporated together by mixing methods.

Sheet Pavement.—A pavement free from frequent joints such as would accompany small slabs or blocks, and which has an appreciable thickness (say in excess of 1 in. on the average) for its wearing course.

Shoulders.—The portion of the highway between the edges of the road metal or pavement and the gutters, slopes, or watercourse.

Side Drain.—See "Drainage."

Sidewalk.—The portion of the highway reserved for pedestrians.

Slag.—Fused or partly fused compounds of silica in combination with lime or other bases, resulting in secondary products from the reduction of metallic ores.

Soil.—A mixture of fine earthy materials with more or less organic matter resulting from the growth and decomposition of vegetation or animal matter.

Solid Bituminous Materials.—Those having a penetration at 25°C. (77°F.), under a load of 100 g. applied for 5 sec., or not more than 10.

Spalls.—Fragments broken off by a blow, irregular in shape, and of sufficient size to be comparable to the original mass.

Squeegee.—A tool with a rubber or leather edge for scraping or cleaning hard surfaces, or for spreading and distributing liquid material over and into the superficial interstices of roadways.

Squeegee Coat.—An application by means of the squeegee.

Stone Chips.—Small angular fragments of stone containing no dust.

Straight-run Pitch.—A pitch run to the consistency desired, in the initial process of distillation, without subsequent fluxing.

Street.—A highway in an urban district.

Subgrade.—The upper surface of the native foundation on which is placed the road metal or the artificial foundation, in case the latter is provided.

Superficial Coat.—A light surface coat.

Surface Coat.—See "Carpet."

Surface Treatment.—Treating the finished surface of a roadway with bituminous material.

Tailings.—Stones which after going through the crusher do not pass through the largest openings of the screen.

Tars.—Bitumens which yield pitches upon fractional distillation and which are produced as distillates by the destructive distillation of bitumens, pyro-bitumens or organic materials.

Dehydrated Tars.—Tars from which all water has been removed.

Telford.—Properly, an artificial foundation advocated by Thomas Telford (1757–1820), and consisting of a pavement of stone about 8 in. thick, laid by hand, and closely packed and wedged together. The individual stones were desired to be about 16 sq. in. in section, and about 8 in. in length. They were set close together on the prepared subgrade, their longest dimension vertical and on their larger ends, their interstices chinked with smaller stones, and the whole rammed (or rolled) until firm and unyielding.

Telford Macadam.—Macadam with an artificial foundation of Telford.

Topped Petroleum.—Petroleum deprived of its more volatile constituents.

Underdrain.—See "Drainage."

Up-keep.—Maintenance.

V-drain.—See "Drainage."

Viscosity.—The measure of the resistance to flow of a bituminous material, usually stated as the time of flow of a given amount of the material through a given orifice.

Volatile.—Applied to those fractions of bituminous materials which will evaporate at climatic temperatures.

Water-bound.—Bound or bonded with the aid of water.

Water-gas Tars.—Tars produced by cracking oil vapors as high temperatures in the manufacture of carburetted water gas.

Wearing Coat.—The superficial layer of the crust or pavement exposed to traffic.

Wearing Course.—The course of the crust or pavement exposed to traffic.

Wood-block Pavement.—One having a wearing course composed of wood paving blocks, generally rectangular in shape.

INDEX

A

Abram's method, 449
Abrasion test, 457, 461
Absorption test for brick, 277
Administration of paving, 18
  of rural highways, 4
Administrative authorities, 8
  county, 6, 9
  municipal, 7, 18
  national, 5, 8
  rural, 4, 10
  state, 5, 9
  township, 6
Aggregates for asphaltic concrete, 389
  for mixed macadam, 358
  portland cement concrete, 259
  sheet asphalt, 375
Aid, national, 8, 17
  state, 9, 17
Alignment, 96
American Society for Testing Materials, 446
Analyses, fluxes, 332
  of pavement costs, 402
  of traffic census, 418
Annual cost of pavement, 404
Appearance of pavements, 424
Applying bituminous materials, 340
  as dust layer, 336
  to penetration macadam, 355
Area method of assessment, 24
Armored curbs, 141
Asphalt, 317, 488
  analyses, 329
    Bermudez, 321
    plants, 394
    Trinidad, 321
  block pavements, 386, 488
    bedding course for, 386
    composition of blocks, 386
Asphalt block pavements, foundation for, 386
    laying, 386
    sand bedding course, 386
      filler, 387
    size of blocks, 386
    subgrade, 386
    tamping blocks, 387
  blocks, composition of, 386
    manufacture of, 386
    size of, 386
  cement, 327, 331, 379, 488
    consistency of, 328, 329, 331
    Cuban, 322
    geological source, 317
    Mexican, 322
    natural rock, 323
    nature of, 317
    origin of, 317
    oil asphalts, 318, 324
    proportioning, 380
    definition of, 319
    fillers, for brick, 285
      for expansion joints, 332
      for stone-block surfaces, 332
      for wood-block surfaces, 332
    petroleum, 321, 324
      residual, 324
    rock, 323
    specifications, 329
Asphaltenes, 484, 488
Asphaltic concrete pavements, 388
  asphalt cement for, 331
  bitulithic, 390
  characteristics, 388, 394
  coarse aggregate type, 389
  construction of, 393
  cross-sections for, 370
  dressing the surface of, 394
  filler for, 389
  foundation for, 391
  maintenance, 394, 435

Asphaltic concrete pavements, mixing and placing, 392, 393
sand for, 389
stone for, 388
thickness of, 392
tools and appliances, 394
Topeka, 390, 391
types of, 389
Warrenite, 390
Assessments for pavements, 20, 27
items of cost assessed, 21
plat of assessments, 22, 26
rural highways, 13, 15
Automobile licenses, 17
operating costs, 409

B

Balancing quantities of earthwork, 105
Base, black, 372
Base, concrete, 233
course for asphalt block pavements, 386
for asphaltic concrete pavements, 391
for brick roads and pavements, 280
for sheet asphalt pavements, 371
for stone-block pavements, 309
for wood-block pavements, 293
Bedding course, asphalt blocks, 386
brick, 281
stone blocks, 312, 313
wood blocks, 301
Bench marks, 38
Benefit of Highway Improvements, 1, 398
curve, 25
factor method of assessments, 13
Bermudez asphalt, 321
Binder course, 373
asphalt cement for, 374
character of materials for, 374
close, 374
made of old surface mixtures, 375
open, 374
rolling, 382
Binder course, spreading, 381
temperature suitable, 383
thickness, 383
Bitulithic, 390
Bitumen, definition of, 319
test for, 482
value of, 320
Bituminous binders, for asphaltic macadam, 330
for carpet coats, 330
for penetration macadam, 330, 362
for portland cement concrete, 330
for sheet-asphalt pavements, 331
carpets, 340
on gravel, 338
concrete, 388
fillers, 284
macadam foundations, 280
roads, 357
road and paving materials, 317
asphalt, 317, 319
Bitumen, 319
Bermudez asphalt, 321
Mexican asphalt, 322
Gilsonite, 322
petroleum asphalt, 324
fluxes, 326
residual asphalts, 324
rock asphalt, 323
tar, 325
Trinidad asphalt, 321
petroleum, 321
water-gas tar, 325
Black base, 372
Blade grader work, 163
Bleeding of wood blocks, 299
Blind drains, 208, 209
Blocks, asphalt, 386
brick, 272
granite, 310
wood, 293
Blown oil, 324
Bonding properties of broken stone, 201
gravel, 189
Bonds, 17

Brick pavements, 272
bedding courses, 281
bituminous filler for, 284
concrete base for, 279
construction of, 287
cross-sections for, 273
curbs for, 281
design, 273
earth subgrade, 287
expansion joints, 285
foundation courses, 278
grout filler, 282
maintenance of, 436
monolithic, 289
roads, 286
rolling, 289
vitrified, 272
absorption, 277
checks in, 274
cross-breaking test, 277
inspection, 289, 464
kiln marks on, 274
kinds of, 274
laminations in, 273
lugless, 275
non-repressed, 275
physical characteristics, 276
rattler loss for, 276
regularity of shape, 277
repressed, 274
requirements of, 277
tests, 462
uniformity of, 277
United States standard sizes, 274
vertical fiber, 275
wearing qualities, 276
wire-cut lug, 275

C

Calcium chloride curing, 268
Camp sites, 109
Car track paving, 150
Carbenes, 485
Catch-basins, 137, 138
Census, traffic, 414
Center line, location of, 35
Central mixing plants, 266
proportioning plants, 266
Characteristics of soil, 159
Classification of highways, 7
of soils, 159
Clay, 159
test for, 456
Cleaning, drainage accessories, 440
ease of, 425
Close binder, 374
Coal tar, 325
distillate oil, 297
paving oil, 297
Coarse aggregates, 260
broken stone for, 260
gravel aggregate, 260
quality of, 259
sandstone for, 261
size of, 261
slag for, 261
Coefficient of friction, 95
Commercial bituminous materials, 327
Comparison of roadways, 405, 426
Computing quantities of earthwork, 105
Concrete, 262
asphaltic, 388
base for pavements, 233, 278
portland cement, roads, 244
contraction joints, 247, 249
cross sections, 244, 245, 246
curbs for, 258
curing, 268, 269
design of, 237
embedded steel, 255
expansion joints for, 247, 251
finishing, 267, 269
fine aggregate for, 262
flumes for, 256
hand finishing, 269
impact on slabs, 226
inlets, 256
loads on, 223, 228, 233
longitudinal joints, 254
machinery used for, 266
maintenance of, 345, 436
materials for, 259
mixing and placing, 267
mixtures for, 262
proportioning, 264

Concrete portland cement, reinforced, 234
resurfacing of, 270, 345
stresses in, 276
temperature effects on slabs, 227
top coating of bituminous material, 345
traffic effects on slabs, 223
two-course, 262
water supply for, 265
Construction of asphalt pavements, 369
brick roads and pavements, 287
car track paving, 150
concrete roads and pavements, 264
country brick roads, 287
curbs and curb and gutter, 136
earth roads, 158
gravel roads, 187
of macadam roads, 201
methods, blade grader, 163
elevating grader, 166
mixed macadam, 357
monolithic brick pavements, 289
penetration macadam, 352
sand-clay roads, 175
sheet-asphalt surfaces, 381
stone-block pavements, 309, 315
wood-block pavements, 292, 305
Contraction joints, 249, 253
Cost of highways, 399, 423
of vehicle operation, 409
of transportation, 413
County, administrative authorities, 9
Creosote for wood preservation, 295
Cross-breaking test for brick, 277
Cross-drains, 129
Crossings, pedestrian, 129
Cross-section for asphaltic concrete pavements, 370
macadam, 357
brick pavements, 273
concrete roads and pavements, 244–246
curbs, curb and gutter, 140, 142
Cross-section for earth roads, 88, 89
gravel roads, 187
macadam roads, 202
main roads, 88
penetration macadam, 352, 353
sand-clay roads, 178
sheet asphalt, 370
stone-block pavements, 309
streets, 112
wood-block pavements, 292, 293
Cross-slope for pavements, 120
for roads, 92
Crown for pavements, 120–122
Crum's method, 447
Cuban asphalt, 322
Culverts, 59
concrete, 61–63, 66
pipe, 63, 64, 67
purpose of, 59
types of, 63
Curb and gutter, combined concrete, 136
construction of, 136
design of, 124
expansion of, 137
foundation for, 137
grades, 119, 125
inlets, 131–135
Curbs, 136
country brick roads, 286
design of, 125, 136, 140, 142
elevations, 125
expansion of, 137
foundation for, 137
height of, 119, 125
integral, 140, 258
materials for, 141
purpose of, 136
radius, 13
settings for, 137
stone, 136
Curing concrete roads, 268
Curling of concrete slabs, 227
Curve, benefit factor, 25
Curves, 98, 100, 104
transition, 98
width on, 99
Cut-back pitches, 325
Cuts, side slope for, 96

D

Definitions of terms employed in highway engineering, 488
Design, of asphalt-block pavements, 386
asphaltic concrete pavements, 388
brick roads and pavements, 272, 286
concrete pavements, 237, 240, 244
culverts, 61, 62
curb inlets, 131
curbs, 136
drainage, 52, 127
gravel roads, 187
macadam roads, 201
mixed bituminous macadam, 357
pavement base, 233, 237, 240
pavements, 111
penetration macadam, 352
rural highways, 87, 286
sheet-asphalt pavements, 369
sidewalks, 141
stone-block pavements, 309
street intersections, 122
streets, 111
wood-block pavements, 293
car track paving, 150
catch-basins, 136–138
combined concrete curb and gutter, 140, 142
concrete slabs, 223
cross-slope, 88, 119
crown, 119
foundations, 223
grades, 71
intersections, 122
ordinary maximum for various surfaces, 117
intersections, 122
manholes, 139
special gutter designs, 139
unsymmetrical streets, 119
width of pavement, 113
Development of highway systems, 1
educational opportunities, 2
financial benefits, 2
social opportunities, 1
Distillation test, 476
Distributors for bituminous materials, 356
Ditches, 52, 53, 96
Dowel steel, 236
Drag, road, 171
use of, 171, 172
Drain tile, loads on, 64
Drainage, pavement, 127
road, 52
Drains, blind, 208
broken stone, 208
cross, 130
tile, 54
Dry batch method, 266
Ductility test, 466
Dummy joints, 253
Dust layers and bituminous carpets, 329, 334
bituminous materials used, 329
and dust suppression on gravel or macadam, 319, 338
suppression, 438

E

Earth roads, computing quantities of earthwork, 105
construction of, 158, 166
cross-sections for, 164
design of, 160
dragging, 171, 172
grades for, 71, 162
machinery for, 169
maintenance, 168, 434
methods of grading, 166
oiling, 329
overhaul, 107
patrolling of, 434
plans for, 46
settlement, 106
shrinkage, 105
side slopes, 96
subsidence, 107
surveys for, 32

Earthwork, 105
Economic comparison of road surfaces, 398
life of highways, 403
computing, 404
theory, 401
Economics, 1, 398, 403
of highway grades, 71
Elevating grader, 164
Embankments, drainage of, 54
Equipment for maintenance, 430
Erosion, 58
Excavation, steam shovel, 165
Expansion joints, for brick pavements, 285
for concrete pavements, 247
for curbs, 137
fillers for, 252, 285
wood-block pavements, 303

F

Factors determining selection of type, 424
Feather-edge method of placing gravel, 193
Federal Authority, 9
Fees, vehicle license, 13, 15
Filler for asphaltic concrete, 389
for sheet asphalt, 376
Fillers, asphaltic, 285, 332
bituminous, 332
for brick surfaces, 282, 285
for stone-block pavements, 314
for wood-block surfaces, 302
mastic, 285
quantity required, 284
tar, 332
Filling expansion joints, 252
Fills, earth, 105
layer method, 107
preparation of site, 163
rolling, 107
side slope, 69, 96
sodding, 69
Finance, 11
Financing rural highway improvements, 14
street paving, 19
Fine aggregate for concrete pavement, 262
Finishing floats, 268
machines, 267
methods, 267, 269
Flash point test, 470
Floats, finishing, 268
test, 467
Flumes, storm water, 256, 257
Fluxes, 326, 332
Foot paths, 109
Fords, 65
Forms for concrete roads, 265
Foundations, 230
drainage, 56
for asphalt concrete surfaces, 391
for asphalt-block pavements, 386
for brick roads and pavements, 278
for curbs, 137
for mixed macadam, 358
for penetration macadam, 352
for sheet-asphalt pavements, 371
for sidewalks, 143
for stone-block pavements, 309
for waterbound macadam, 203, 204
for wood-block pavements, 293
Fresno scrapers, 165, 169
Front foot rule for assessments, 22
Fuel taxes, 13, 15

G

Gang maintenance, 434
General benefits, 14
Gilsonite, 322
products, 324
Glossary of road terms, 488
Grade reduction, 162
Grader, blade, 163
elevating, 164
Fresno, 165
Maney, 165
Grades at curb corners, 11, 125, 127, 148, 149, 153
between platforms, 148
for animal-drawn vehicles, 84, 97
for pavements, 116, 117

Grades at curb corners, for rural highways, 71
for self-propelled vehicles, 71, 97, 105
Grading, appliances, 166, 169
balancing quantities, 160
earth roads, 162
for gravel, 188, 189
for oiling, 334
methods of, 166
rural highways, 105, 166
tables of, for asphaltic concrete, 389, 391
for sheet asphalt, 378, 379
for Topeka, 390, 391
Gravel aggregates for concrete roads, 259
bonding properties, 189
coated earth roads, 195
roads, 187
carpet coats for, 344, 347
characteristics of, 196
cost of, 195
cross-sections for, 187
cross-slope for, 192
crown, 192
dust layers for, 195, 347
feather-edge method of placing, 193
foundation for, 193
grading, 190
harrow for, 214
ideal materials, 188, 189
maintenance of, 195, 436
placing gravel, 192
preparation for, 191
roadbed for, 191
rolling, 193
selection of gravel, 190
tools and machinery for, 213
trench method, 192
washed gravel, 194
wearing properties, 189
Grooved rails, 152
stone blocks, 311
Ground water, 54
Grout filler for brick, 282
for stone blocks, 314
for wood blocks, 307
Grout filler, mixer for, 283
mortar box for, 283
proportioning of, 282
Guard fence, 108
Guide and warning signs, 108
Gutters, depth of, 126, 129
Gypsum roads, 180

H

Harrows, 214
Headwalls for culverts, 65
Heaters, sand and stone, 361
Height of curbs, 136
Highway bonds, 17
costs, 399, 408
engineering, 3
finance, 11, 12, 19
systems, development of, 1
Highways, basis of value, 400
economic life of, 403
computing, 404
theory, 398
initial cost, 402
life tonnage, 400
maintenance cost, 402
right of way costs, 406
roadway surface costs, 401, 406
salvage value, 403, 406
table of highway cost, 406
diagram of, 402, 408
value of, 399

I

Impact on roads, 225
stresses, 226
Initial cost of highways, 402
Inlets, storm water, 256
Inspection of brick, 289, 464
wood blocks, 301
Integral curbs, 140
Intersections, 122, 144, 145, 147–149

J

Jackson specific gravity test, 459
Joint fillers, 252

Joints, dummy, 254
expansion, 227, 247
brick pavements, 285
concrete pavements, 247

L

Laying asphalt blocks, 386
asphaltic concrete, 388, 393
brick, 289
sheet-asphalt, 381, 382
stone-blocks, 313
wood blocks, 302, 305
Le Chatelier test, 458
Levels, branch roads, driveways, 39
Licenses, vehicle fees, 15
Life of pavements, 400
tonnage, 400, 403, 406
Lipped rails, 152
Loading devices for road materials, 214
Loads on drain tile, 64
on highways, 224, 228, 233
Local materials, 426
Longitudinal cracks, 227, 254
joints, 254
steel, 235
Loss on heating test, 474
Lugless brick, 275

M

Macadam base, 201, 280, 352, 358, 373
oil mix, 360
penetration, 352
size of stone, 203
Telford, 204
thickness of, 205
tools and machinery, 213
waterbound, 201
applying screenings, 211, 219
blind drains, 208, 209
carpet coats on, 344
construction of, 204, 207
cross-sections for, 202
dust layers, 338
harrowing, 209
maintenance of, 212, 436
Macadam base, waterbound, materials required, 216
placing stone, 207, 218
puddling, 211, 220
quality of rock, 201
roadbed and shoulders, 206
rolling, 209, 210, 215
size of stone, 203
crusher run, 203
sledge-stone base, 221
wearing properties, 201
Machinery, asphalt plants, 394
for concrete road and pavement construction, 265
for earth road construction, 169
for finishing concrete, 267
for grading, 169
for macadam and gravel road construction, 213
for mixed macadam, 361
for penetration macadam, 355
Maintenance, 428
costs, 402, 406, 407
general, earth roads, 432, 434
influence on selection, 426
methods of, earth roads, 430
of asphaltic concrete surfaces, 394, 435
of brick roads, 436
of concrete roads and pavements, 436
of earth roads, 430
of gravel roads, 195, 435
of macadam roads, 212, 435
of rural highways, 429, 435
of sand-clay roads, 183
of sheet-asphalt surfaces, 435
of surfaced roads, 433
Maney grader, 170
Manholes, design of, 139
Manufacture of wood blocks, 300
Mastic filler, 285
Material for sheet asphalt, 373
for stone blocks, 310
for wood blocks, 293
Materials, bituminous, 317
tests for, 466
for asphalt blocks, 386
for asphaltic concrete, 388

Materials for binder, sheet asphalt, 375
for brick pavements, 272
for concrete roads, 259
for curbs and curb and gutter, 141
for gravel roads, 188, 198
for macadam, 201, 206, 216
for mixed macadam, 354, 362
for penetration macadam, 353, 362
for sand-clay roads, 175
for sheet asphalt, 375
Maximum grades for pavements, 116
Measuring concrete materials, 264
Melting tanks for bituminous materials, 361
Mexican asphalt, 322
Minnesota road planer, 171
Mixed bituminous macadam, 357
cement for, 330
foundation of, 358
gravel aggregate for, 358
mechanical appliances used, 358, 361
proportioning, 358
seal cost, 359
stone for, 358
wearing surface for, 358
Mixers for bituminous concrete, 359, 392, 394
macadam, 361
portland cement concrete, 267
sheet-asphalt surfaces, 392, 394
Mixing asphaltic concrete, 393
bituminous macadam, 358, 359
plants for sheet surfaces, 394
portland cement concrete, 267
sheet asphalt, 392
Mixtures, bituminous, 361, 378, 389
of concrete, 262
of tar and creosote, 296
Moisture in concrete, 228
Monolithic brick pavements, 289
Mortar bedding course for brick, 282
cushion for stone blocks, 313
for stone blocks, 313
for wood blocks, 301
Motor vehicle operating costs, 409, 411

N

National aid, 5, 15, 17
highway system, 7
Natural asphalts, 321
refining of, 323
rock asphalts, 323
Non-repressed brick, 275
Notes, survey, 37, 40

O

Oil asphalt, 318
mix macadam, 360
on hard pavements, 340
storage, 435
Older's theory of design, concrete slabs, 238
Open binder, 374
Ordering pavements, 30
Organic impurities, test for, 461
Organization, maintenance, 429
Overhaul, 107

P

Paint coat bedding course, 301
Palliatives other than oil, 340
Pat test, 380
Paving brick, 272
kinds of, 274
size of, 274
tests for, 276
car track, 150–153
plans, 49
surveys for, 47
Pedestrian crossings, 129
Penetration macadam roads and pavements, 352
applying bituminous binder, 355, 356
bituminous material for, 330
construction of, 352
cross-sections for, 352, 353
foundation, 352
Patrol maintenance, 430
Pavement foundations, 223
Pavements, asphalt-block, 386
asphaltic concrete, 388

Pavements, assessments for, 20
brick, 272
concrete, 244
design of, 111
drainage of, 127
life of, 403, 406
macadam, 201
monolithic brick, 289
repairs on, 437
selection of, 423
sheet-asphalt, 369
stone-block, 309
width of, 113
wood-block, 292
Paving blocks, stone, 310
Penetration macadam, rolling, 354
size and kind of stone, 353
thickness, 352, 353
wearing course, 354
Petroleum asphalts, 324
Physical characteristics of pavements, 424
Pipe culverts, 63
Pitch filler, 332
grouted macadam surfacing, 366
Pitches, cut-back, 325
Plans, paving, 49
road, 46
Plants, central mixing, 266
sheet asphalt mixtures, 376
Platform grades, street, 154
Platforms, definition of, 153
Pouring bituminous filler, 284
cans, 355
Preservative treatment for wood blocks, 295
Pressure distributing wagons, 356
Principles of concrete slab design, 223
Profile, 46, 49
Property benefits, special, 15, 19
Proportioning asphalt cement, 396
asphaltic concrete mixtures, 396
grout filler, 282
mixed bituminous macadam, 358
portland cement concrete for roadway surfaces, 264, 266
Protection of slopes, 69

Q

Quality of rock for asphaltic concrete, 388
for macadam, 201
for mixed macadam, 358
for portland cement concrete surfaces, 259
Quantity of bituminous cement for asphaltic concrete, 390, 391
for asphalt blocks, 386
for mixed macadam, 358
for sheet asphalt, 376, 379, 380
of filler for brick, 284
of stone for macadam, 217

R

Radius curbs, 124
Rails, 151
Rakes, 396
Raking asphalt mixtures, 382
Reconnaissance survey, 32
Reduction of grades, 162
Refining asphalts, 323
Reinforced concrete culverts, 59
roads and pavements, 234
Repressed vitrified brick, 275
Residual asphalts, 324
Resurfacing concrete roads and pavements, 270
Right of way, 87
Road drags, types of, 171
use of, 171
graders, 169
material testing, 446
planer, 171
plans, 46
Roads, asphaltic concrete, 388
brick, 272
design of, 87
earth, 158
gravel, 187
gypsum, 180
local, 6
macadam, 201
main market, 6
mixed macadam, 357
national, 5

Roads, penetration macadam, 352
portland cement concrete, 244
rural, design of, 87
sand-clay, 175
state, 5, 9
township, 6, 10
Roadway surface costs, 401
selection of, 423
Rock asphalt, 323
Rollers, 210
self-propelled, 215, 383, 388
tandem, 397, 383
three-wheeled, 210, 215, 388
Rolling asphaltic concrete, 388
bedding course for brick, 288
brick surfaces, 289
earth fills, 107
gravel, 193
macadam, 209
mixed macadam, 360
penetration macadam, 354
resistance, 81, 85
sheet asphalt, 383
Telford, 205
wood blocks, 303
Runoff, 52

S

Salvage value of highways, 403
Sand bedding course, for brick, 281
for stone blocks, 312
for wood blocks, 301
cushion, 281
heaters, 395
mortar bedding course, 282
for asphaltic concrete, 389
bedding course, 281
portland cement concrete surfaces, 262
sheet asphalt, 375
Sand-clay roads, 175
characteristics of, 180
construction of, 177, 181
cross-sections for, 178
durability of, 183
for gumbo, 177
for loam, 177
for sand, 179
maintenance of, 183
Scrapers, wheel or Fresno, 165
Screens for sheet asphalt plants, 395
Seal cost, 394
Seasoning wood blocks, 300
Selection of pavements, 30
of roadway surfaces, 423
appearance, 424
color, 424
cost considerations, 423
dustlessness, 424
ease of cleaning, 425
existing types, 426
foothold, 425
maintenance organization, 426
physical characteristics, 424
special local considerations, 425
local materials, 426
of type of roadway, 421
Settlement of embankments, 106
Sheet-asphalt, 369
asphalt cement for, 331, 379
binder course for, 373, 375
black base for, 372
characteristics of, 385
construction of, 381
cross-sections of, 370
design of, 369, 384
fillers for, 376
foundation for, 371, 373
mixing plants for, 394
old surface mixtures for binder, 375
pavements, 369
pat test, 380
plants, 394
proportions of materials, 376, 380
rolling, 383
sand for, 375
standard gradings for, 378
surface mixtures, 375
Shoulders for macadam, 206
Shrinkage of earth fills, 105
Side ditches, 52
slope, in cuts, 96
on fills, 69, 96
Sidewalks, 141
Sieve analysis, method, 455, 456
Sieves, standard for road materials, 452

Signs, guide and warning, 108
Size of asphalt blocks, 386
brick, 274
coarse aggregate for asphaltic concrete, 388
for concrete base, 233
roads and pavements, 261
curb expansion joints, 137
sand for asphaltic concrete, 389
for bedding course, 281, 301, 312, 313
for concrete roads and pavements, 262
for sheet asphalt, 375
stone blocks, 310
of stone for waterbound macadam, 203
wood blocks, 293
Slag for coarse aggregate, 261
bedding course, 282
Slip scrapers, 169
Slipperiness, 96
Slopes, protection of, 69
drainage ditches, 52, 53
Slump test, 458
Smoothing irons, 397
Smoothness of pavements, 384
Snow removal, 437, 440
Sodium silicate, 269
Softening point, 479
Soils, characteristics of, 159
Soundness test, 457
Sources of bituminous materials, 321
Special assessments, 20, 27
Specification for asphalt blocks, 386
cement, 329
for binder course, 373
for bituminous binders, 330, 362
for creosote oils, 295
for pitch, Great Britain, 326
Specific gravity test, 457, 458
Spreading asphalt mixtures, 382
Squeegee method of filling, 284
Staking center line, 35
Standard asphaltic concrete, 389–391
commercial stone, 454
gradings, sheet asphalt, 378
Standard lugless brick, 275
practices in superelevation, 100
sieves, 449, 452, 453
State aid, 9, 17
authority, 9
bonds, 17
Steam shovel excavation, 165
Steel, embedded, 255
Stone, blocks for pavements, 310
crushing plants, 215, 216
cubes, 311
curbs, 136
drains, 208, 209
for asphalt blocks, 386
for asphaltic concrete, 388
for macadam, 203, 216
for mixed macadam, 358
for penetration macadam, 353
for portland cement concrete road surfaces, 259
forks, 213
heaters, 395
rakes, 213
screenings for bedding course, 281
Stone-block pavements, cross-section for, 309
foundation for, 309
grooved blocks for, 311
grout filler for, 314
kinds of stone used, 310
laying blocks, 313
mortar bedding course for, 313
pitch filler for, 314
recut blocks for, 314
requirements for stone blocks, 312
sand bedding course, 312
size of blocks, 310
special kinds of, 311
tamping the blocks, 313
uniformity of, 311
Storage bins for hot aggregates, 395
Street cleaning, 439
sprinkling, 439
intersections, design of, 122
maintenance, 437
paving, administration of, 18
Stresses in concrete roadway surfaces, 226, 228

Strike boards for concrete surfaces, 267, 269
Subgrade, 230, 264
  drainage, 56, 96
Subsidence, 107, 232
Superelevation, 93
  table of standard practice, 100
Surface drainage, 52
  mixtures, asphaltic concrete, 389
    for mixed macadam, 357
    for sheet asphalt, 376
    for Warrenite, 390
  oiling, 334
    tarring, Great Britain, 362
Surveys for roads, 32
  complete detailed, 33
  construction, 42
  for earth roads, 33
  paving, 47
  reconnaissance, 34
  traffic, 414
Systems of administration of highways, 4
  county, 9
  municipal, 18
  national, 8
  state, 9
  town, 10
  township, 10

T

Table of, annual transportation costs, 413
  A.S.T.M. standard sieves, 452
  automobile operating costs, 409, 412, 413
  area of culvert waterways, 60
  asphalt block composition, 386
  bitulithic mixture, 390
  brick, paving, sizes of, 274
  characteristics, composite automobile, 74
  coarse graded asphaltic concrete, 389
  coefficient of friction, 95
  comparison of light and heavy creosote oils, 298
  composite commercial vehicles, 74
Table of cost of roads, 406
  effect of road condition on cost, 411
  linear feet of road per cubic yard of stone, 217
  loads on drain tile, 64
  maximum grades for pavements, 117
  oiling costs, 338
  penetration limits, asphalt, 328, 331
  proportions and quantities, concrete, 450, 451
  quantity of stone for roads, 217
  rattler loss, paving brick, 276
  sieve analysis, asphalt concrete, 389
    sheet asphalt, 379
  standard broken stone, 454, 455
    paving brick, 274
    sheet-asphalt grading, 378
    specifications, asphalt sand, 378
  stone blocks, size of, 312
  superelevation, standard practices, 100
  Topeka grading, 390, 391
  tractive resistance of roadway surfaces, 85
  traffic summary, Chicago, 419
    weights, 417
  transportation costs, 413
  U. S. Standard Sieves, 453
  vehicle operating costs, 409, 412 413
  weights of traffic units, 417
  zone and area method of assessment, 23, 24
Talbott's formula for waterways, 60
Tampers for sheet surfaces, 384, 397
Tamping asphalt blocks, 387
  stone blocks, 313
Tar, gas-house, 325
    macadam surfacing, 352, 362
    water gas, 325
  surfacing, Great Britain, 362
    specification for tar, 362, 363
Taxes, road, 14
Telford macadam construction, 104, 206, 221

Temperature stresses, 226
Tests of Road Materials, methods of, 446
Abrams' Tables, 449–451
abrasion for rock, 457
for gravel, 461
absorption, 457
asphaltenes, 484
bitumen, total, 482
carbenes, 485
commercial gravel, 454
stone, 455
Crum's method of proportioning, 447, 448
distillation, 476
dustility, 466
extraction, 485
flash and fire, 470
float test, 467
loss on heating, 474
organic impurities, 461
penetration, 472
rattler test for brick, 462
sieve analysis of broken stone, 456
sand, 455
sieves, 449, 452, 453
silt and clay, 456
slump, 458
softening point, 479
soundness, 457
specific gravity, 457, 458
total bitumen, 482
toughness, 460
viscosity, 485
Theory of design, concrete pavements, 237
Timber for wood blocks, 293
Tools and machinery for gravel and macadam construction, 213
Topeka asphaltic concrete, 390, 391
Toughness test, 460
Township or town roads, 6, 10
Track pavement construction, 150
Tractive resistance, 81, 85
Traffic, 3, 71, 403
census, 414
character of, 71
on pavements, 91
special benefits to, 13
Traffic surveys, 414
through motor, 3
volume of, 91
weighing, 415
weight of, 417
zones, 421
Transportation costs, 413
Transition curves, 98
Trench method of placing gravel, 192
Treating wood blocks, 298
Trinidad asphalt, 321
petroleum, 321
Two-course concrete roadway surfaces, 262

U

Underdrainage, 52
Unit of measure of highway value, 400
Unsymmetrical streets, 119

V

Value of a highway, 399, 400
Vehicle costs, 409
Vertical fiber brick, 275
Viscosity test, 485
Vitrified brick roads and pavements, 272

W

Warning signs, 108
Warrenite—Bitulithic, 390
Washed gravel, 194
Water supply for concrete roads, 265
Waterbound macadam, 201
Water-gas tar, 325
Waterways, Talbott's formula for, 60
Weighing traffic, 415
Weights of macadam materials, 218
Wet batch method, 266
Wheel loads, 223
scrapers, 165, 169
Width of streets, 116
on curves, 99

Wire cut lug brick, 275
Wood blocks, 293
  inspection of treatment, 301
  manufacture of, 295
  preservative treatment, 295, 300
  quality of, 294
  seasoning, 300
  size of, 294
  timber used, 293
Wood-block pavements, 292
  bedding courses for, 301
  bleeding, 299
  characteristics of, 303
  construction of, 302
  creosote oils employed, 295
  cross-section for, 292
  crown of, 293
  curbs for, 293
  design of, 293
Wood-block pavements, durability of, 292, 303
  expansion joints, 303
  fillers for, 302
  foundation for, 293
  manufacture of blocks, 300
  mastic bedding course, 301
  mortar bedding course, 301
  preservative treatment of blocks, 298
  quality of blocks, 293
  sand bedding course, 301

Z

Zone and area method of assessment, 24
  plat of, 22
  table illustration of, 23
Zones, traffic, 24, 421